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O'Neill, Kathleen

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Analysis of Chilled Water Free Cooling
at the
Perimeter Center Office Park (Atlanta, Georgia)

35789

Kathleen O'Neill
submitted to:

Dr. W.H. Wepfer
Dr. S.V. Shelton

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Thesis
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Energy conservation is an important part of any HVAC system design and operation today. One of the most common energy conservation measures used in water side economizer systems is free cooling. However, it is difficult to evaluate the potential for savings of the impact of free cooling without a detailed analysis. In order to better understand the potential impact of free cooling operations, data on an existing system from a ten year period was compared with the ambient climatic conditions. As will be discussed, for all but the hottest summer months, free cooling accounted for a significant percentage of the system's operating hours. By comparing actual weather data with the free cooling data, the ambient dry bulb switchover temperature for Atlanta was found. This procedure can easily be duplicated for other climates.

As part of its energy conservation program, the Perimeter Center Office Park in Atlanta, Georgia has used free cooling in the HVAC systems of its low-rise(one to two story) and mid-rise(three to ten story) buildings. The HVAC system for each group of buildings consists of a 150 to 250 ton central chiller with multizone air handlers and electric duct heating. The system incorporates a water-side economizer using the cooled tower water directly in the chilled water system. In free cooling, the switchover temperature is the dry or wet bulb temperature at which the system switches from its conventional mechanical cooling operation to free cooling. The systems in this analysis switch into the free cooling mode on a fixed tower sump water temperature. During the periods of free cooling, the water discharged from the cooling tower is circulated directly through the chilled water circuits, including the air handling units and tower fans operate continuously.

The critical unknown in the system's switchover to free cooling is the ambient dry bulb temperature which corresponds to the tower sump water temperature for a given month or year. Finding the corresponding ambient dry bulb switchover temperature for the systems was the purpose of this analysis. For each of the fifteen building groups in Perimeter Center, data on the number of chiller operating hours and the number of

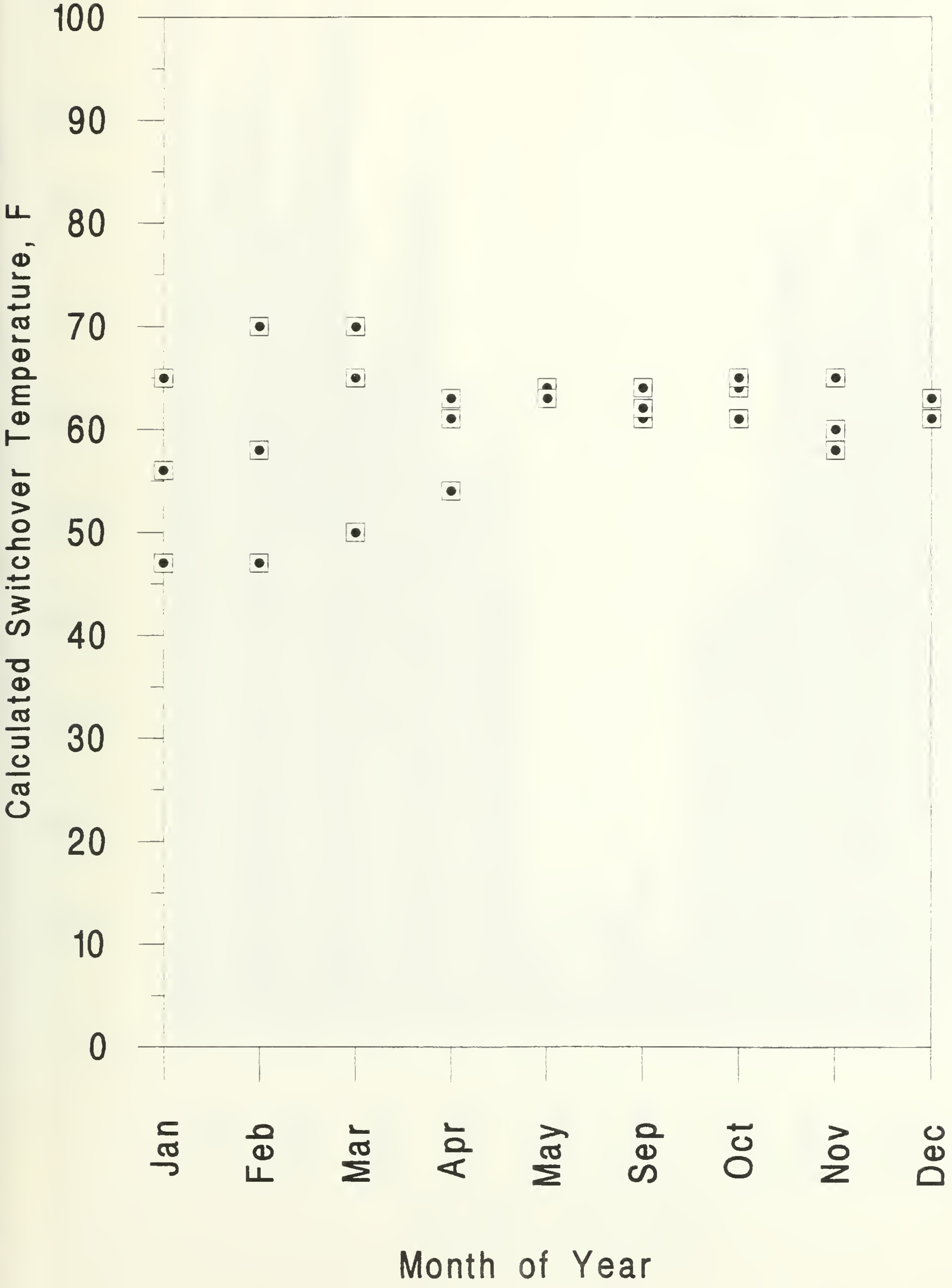
bypass hours is collected each month. Inputting the data into spreadsheets makes calculating the percentage of free cooling for a given month simple. With these percentages, a corresponding ambient dry bulb temperature can be found with a simple program which compares the percent free cooling with the number of hourly dry bulb temperatures which are below a set value. The Perimeter Center is occupied between 0600 and 1900 daily, so only temperatures during this period were considered. For this comparison, the Naval Oceanographic Command Detachment, Asheville, North Carolina provided hourly dry-bulb temperature data for Atlanta for the years analyzed. For each year, however, the months of June, July and August yielded no significant savings from free cooling and were excluded from the final calculations of the average switchover temperature and average percentage free cooling for each class of buildings. In Atlanta, the data showed that the seasonal transitional months of May and September did yield significant percentages of free cooling and were included.

There are two important which resulted from this analysis. One, that the system operates in the free cooling mode a significant percentage of the time, excluding Atlanta's hottest months of June, July and August. The midrise buildings on average operated in the free cooling mode 38 percent of the operating hours for all months exclusive of June, July and August, yielding an ambient dry-bulb switchover temperature of 56 °F. If the seasonal transitional months of May and September are excluded, the midrise buildings operated in the free cooling mode 49 percent of the time. The low rise structures averaged free cooling for 49.5 percent of the time, yielding a dry bulb switchover temperature of 61°F. From this analysis, a strong case is made for the potential savings using free cooling in a moderate climate like Atlanta's. However, this analysis could easily be duplicated to yield similar results for different climates.

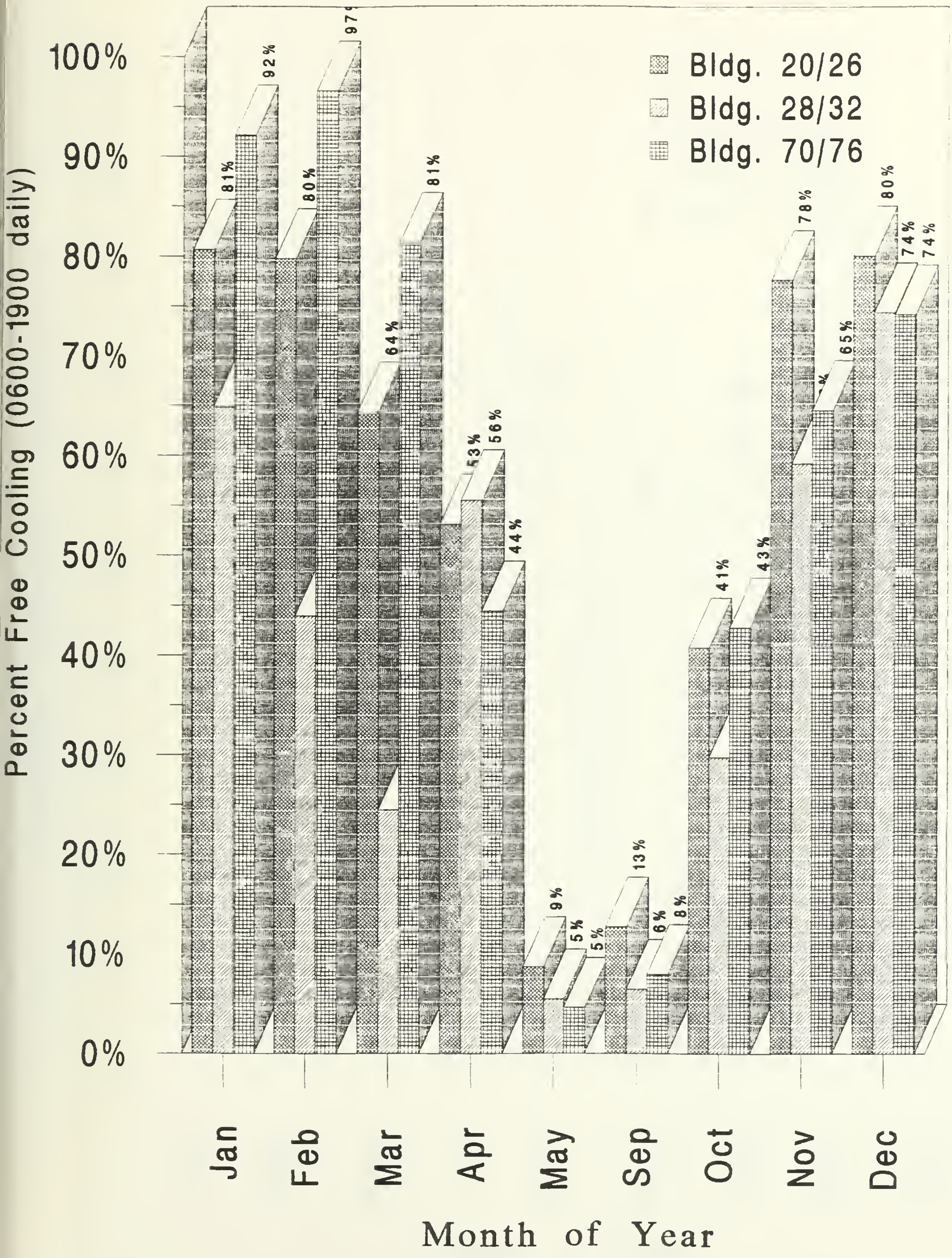
APPENDIX A

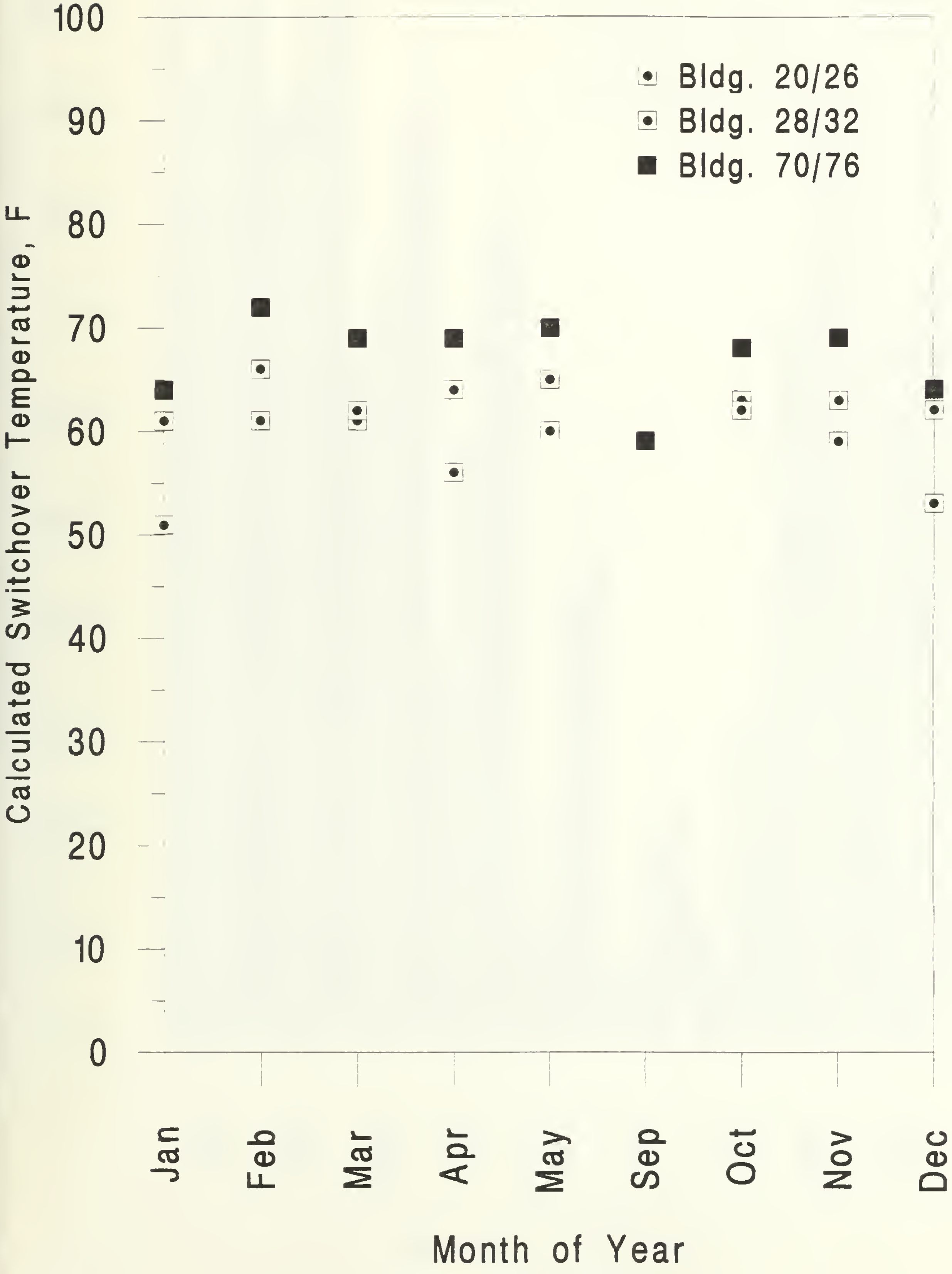
Graph I Monthly Percent Free Cooling (Low-rises, 1982)
Graph II Calculated Free Cooling Switchover Temperature (Low-rises, 1982)
Graph III Monthly Percent Free Cooling (Low-rises, 1984)
Graph IV Calculated Free Cooling Switchover Temperature (Low-rises, 1984)
Graph V Monthly Percent Free Cooling (Low-rises, 1986)
Graph VI Calculated Free Cooling Switchover Temperature (Low-rises, 1986)
Graph VII Monthly Percent Free Cooling (Low-rises, 1988)
Graph VIII Calculated Free Cooling Switchover Temperature (Low-rises, 1988)
Graph IX Monthly Percent Free Cooling (Mid-rises, 1982)
Graph X Calculated Free Cooling Switchover Temperature (Mid-rises, 1982)
Graph XI Monthly Percent Free Cooling (Mid-rises, 1984)
Graph XII Calculated Free Cooling Switchover Temperature (Mid-rises, 1984)
Graph XIII Monthly Percent Free Cooling (Mid-rises, 1986)
Graph XIV Calculated Free Cooling Switchover Temperature (Mid-rises, 1986)
Graph XV Monthly Percent Free Cooling (Mid-rises, 1988)
Graph XVI Calculated Free Cooling Switchover Temperature (Mid-rises, 1988)
Graph XVII Monthly Average Percent Free Cooling, Lowrises (Summary, All Years)
Graph XVIII Calculated Free Cooling Switchover Temperature for Lowrise Buildings (Summary, All Years)
Graph XIX Monthly Average Percent Free Cooling, Midrises (Summary, All Years)
Graph XX Calculated Free Cooling Switchover Temperature for Midrise Buildings (Summary, All Years)

Calculated Free Cooling Switchover Temperature (Low-rises, 1982)

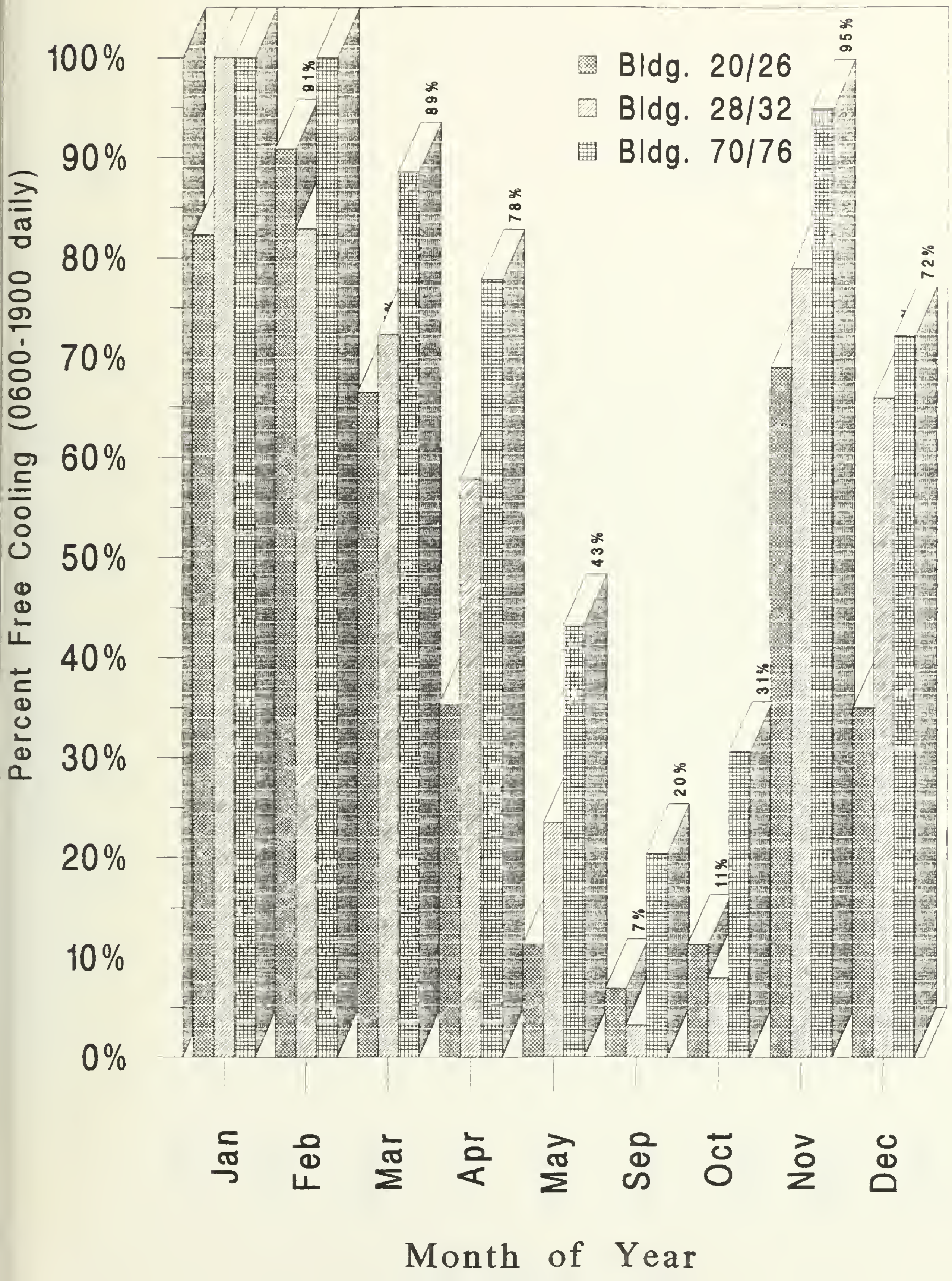


Monthly Percentage of Free Cooling
(Low-rises, 1982)

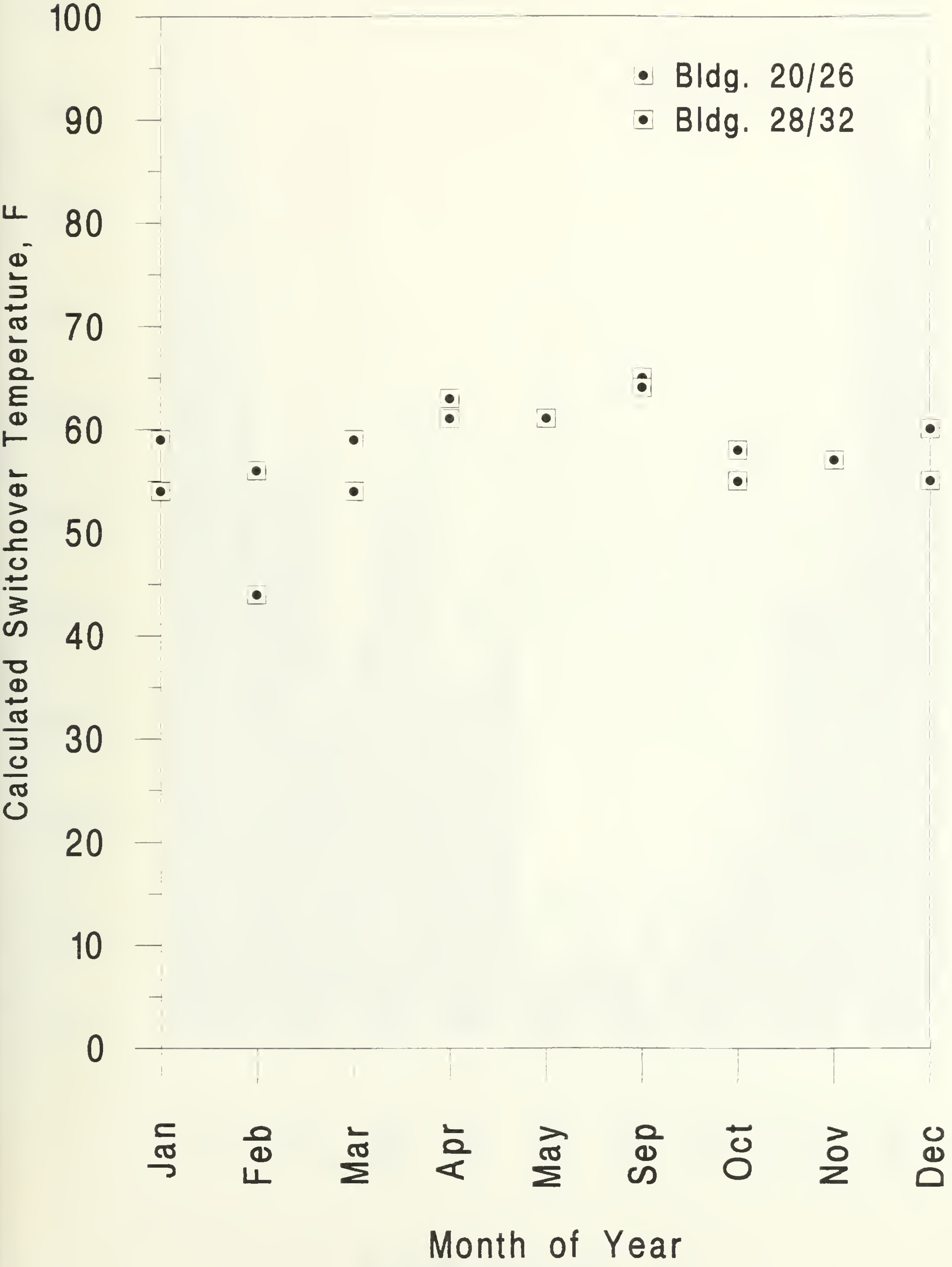


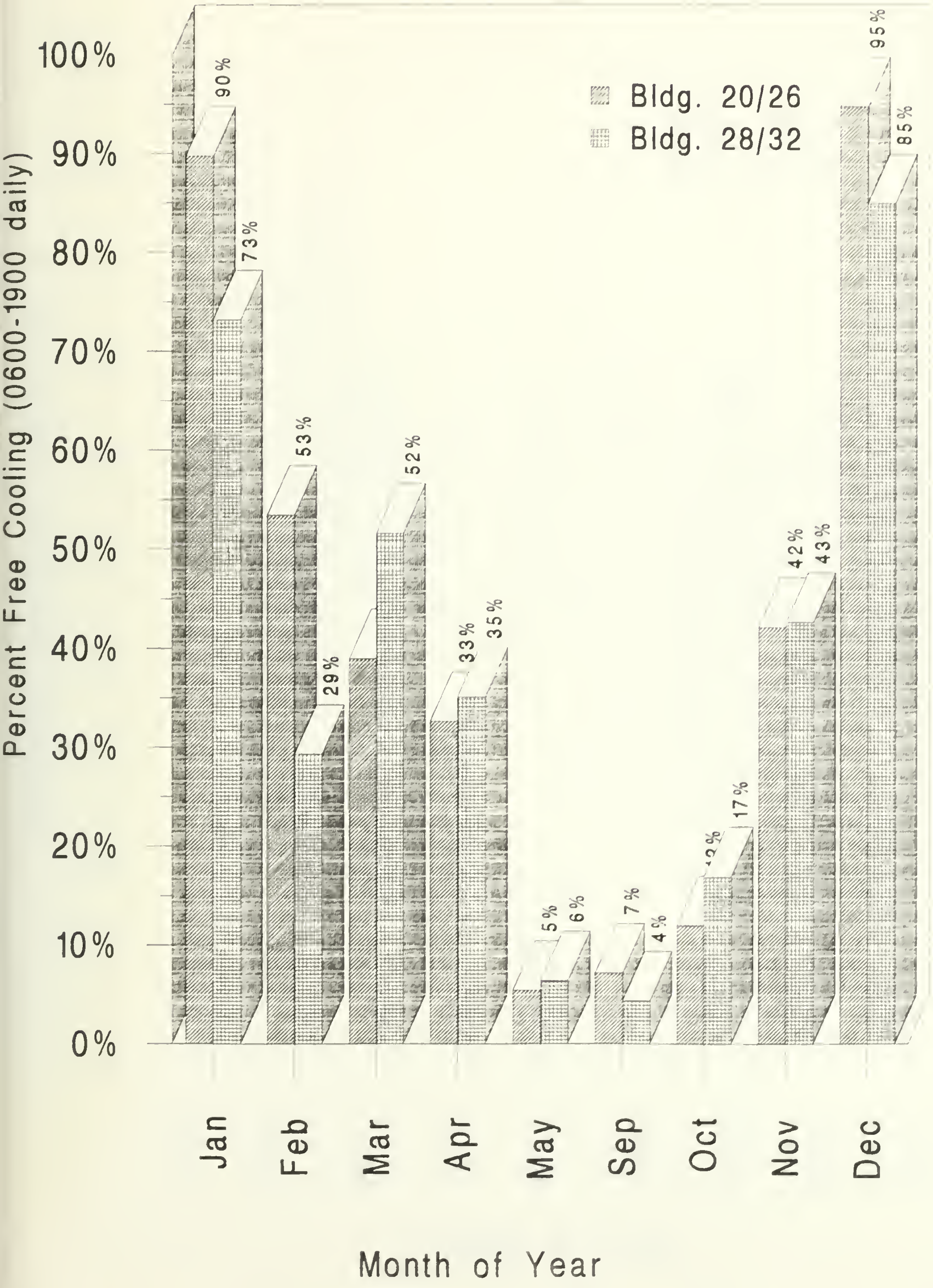

Calculated Free Cooling Switchover Temperature (Low-rises, 1984)

Monthly Percentage of Free Cooling
(Low-rises, 1984)

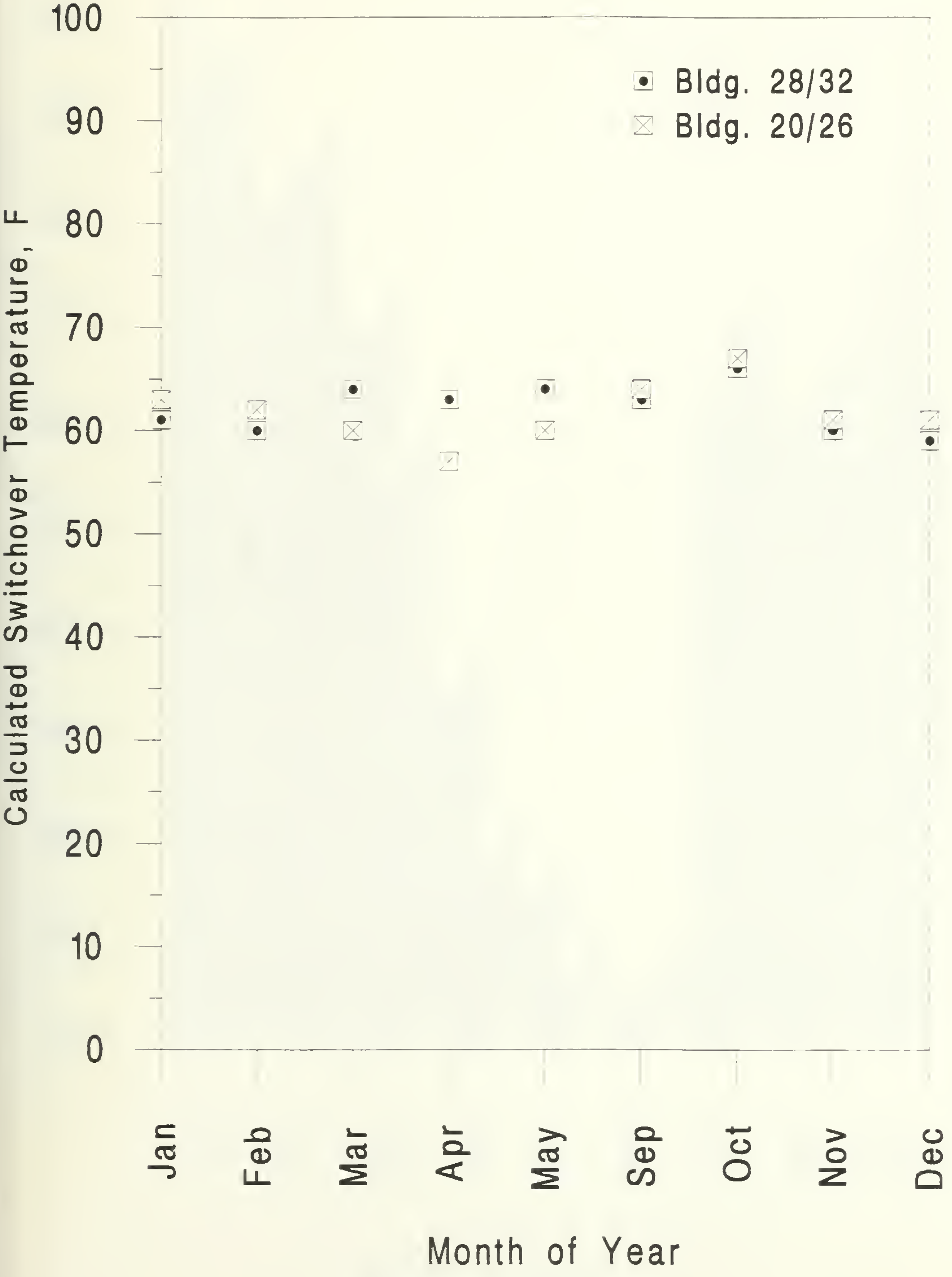


Calculated Free Cooling Switchover Temperature (Low-rises, 1986)



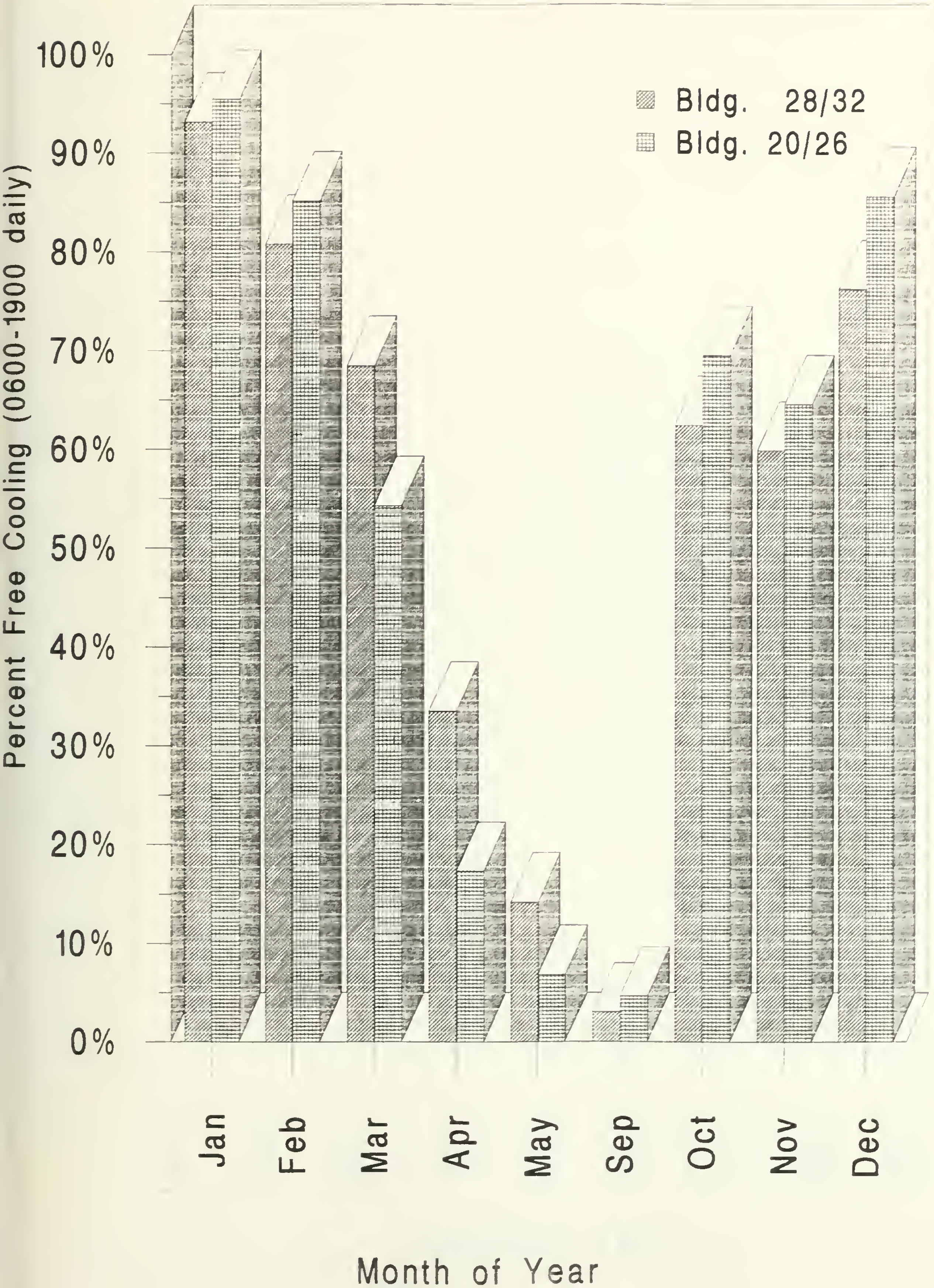


Monthly Percentage of Free Cooling
(Low-rises, 1986)

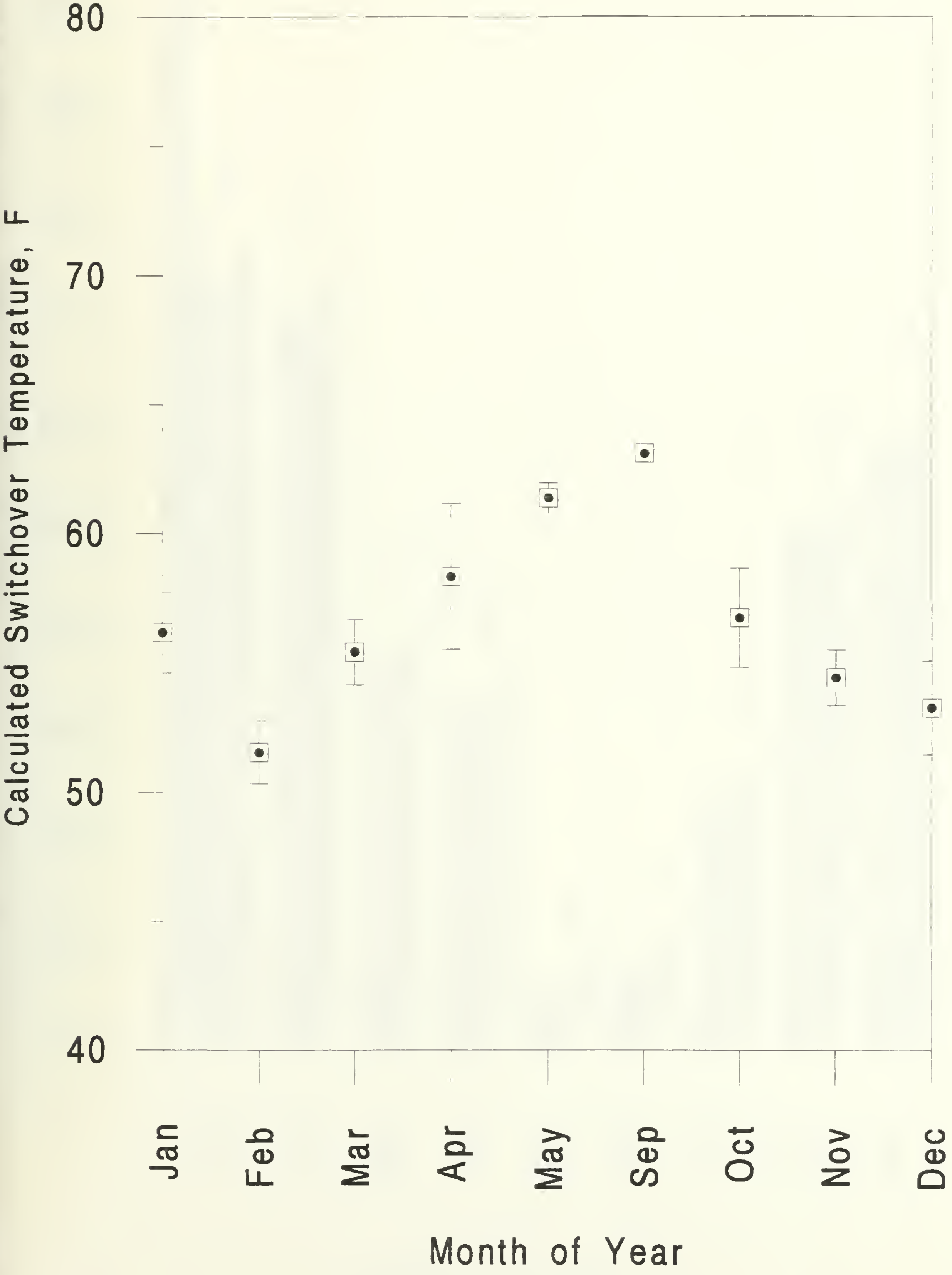


Calculated Free Cooling Switchover Temperature (Low-rises, 1988)

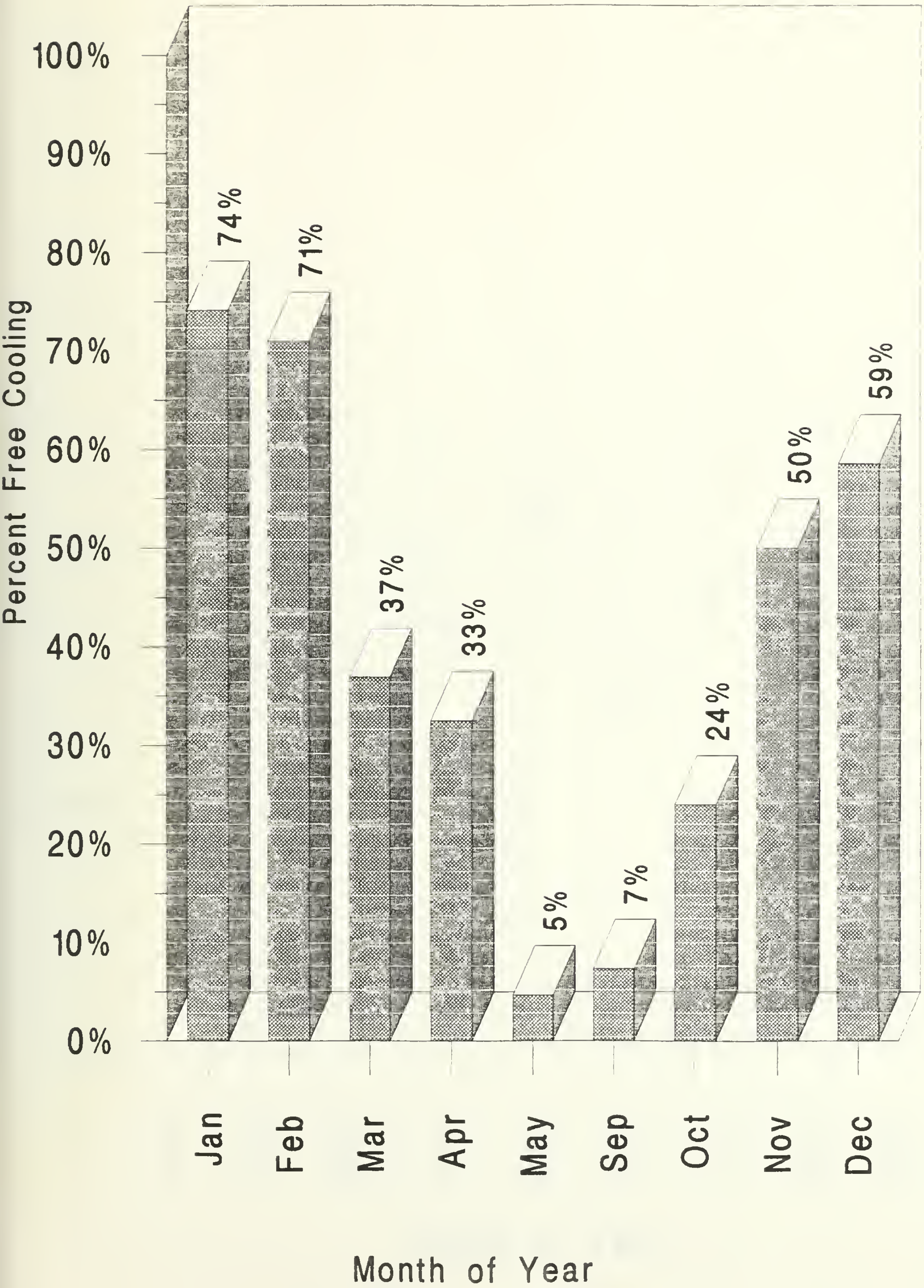
Monthly Percentage of Free Cooling (Low-rises, 1988)



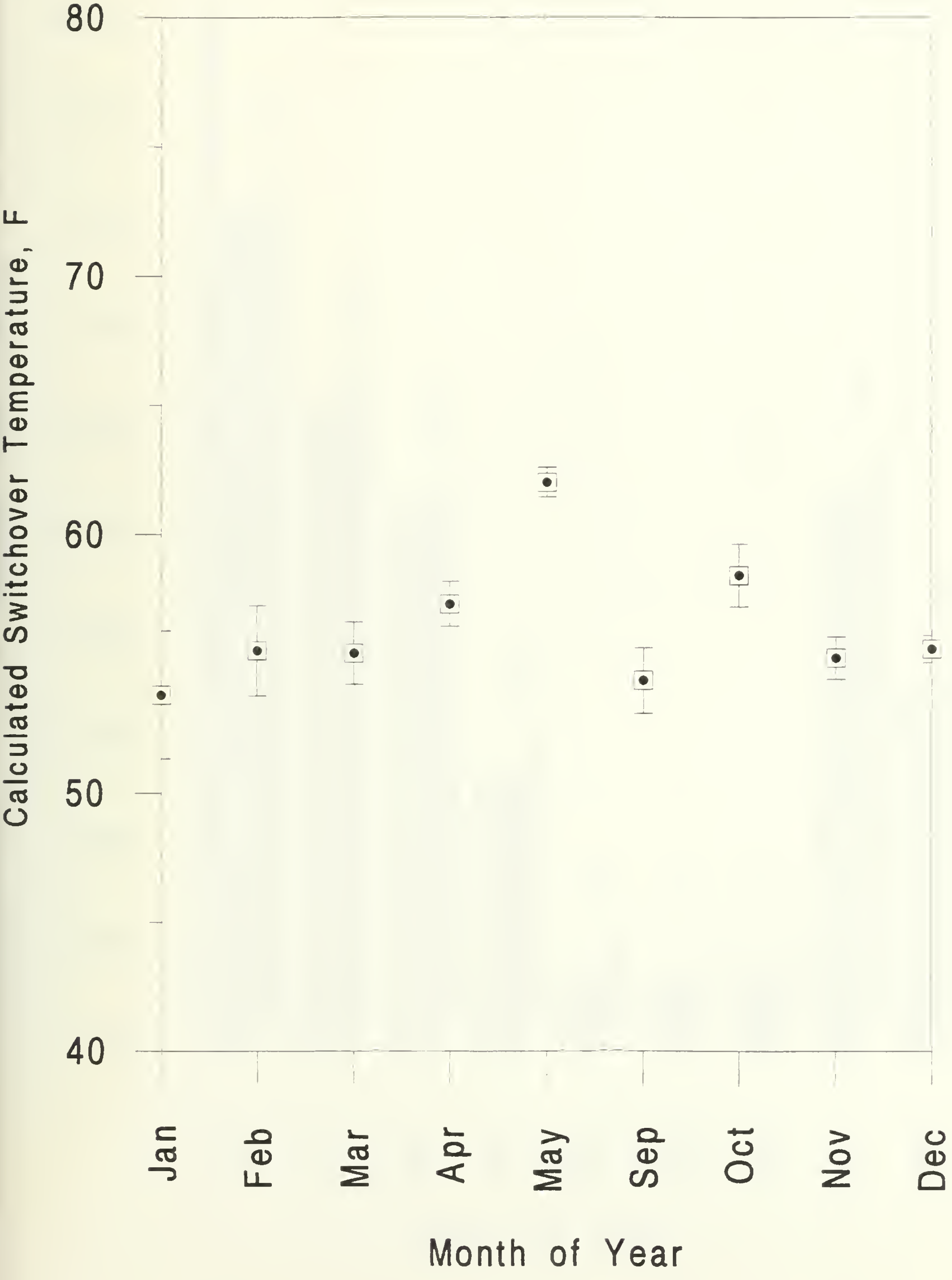
Calculated Free Cooling Switchover Temperature, (Midrises, 1986)

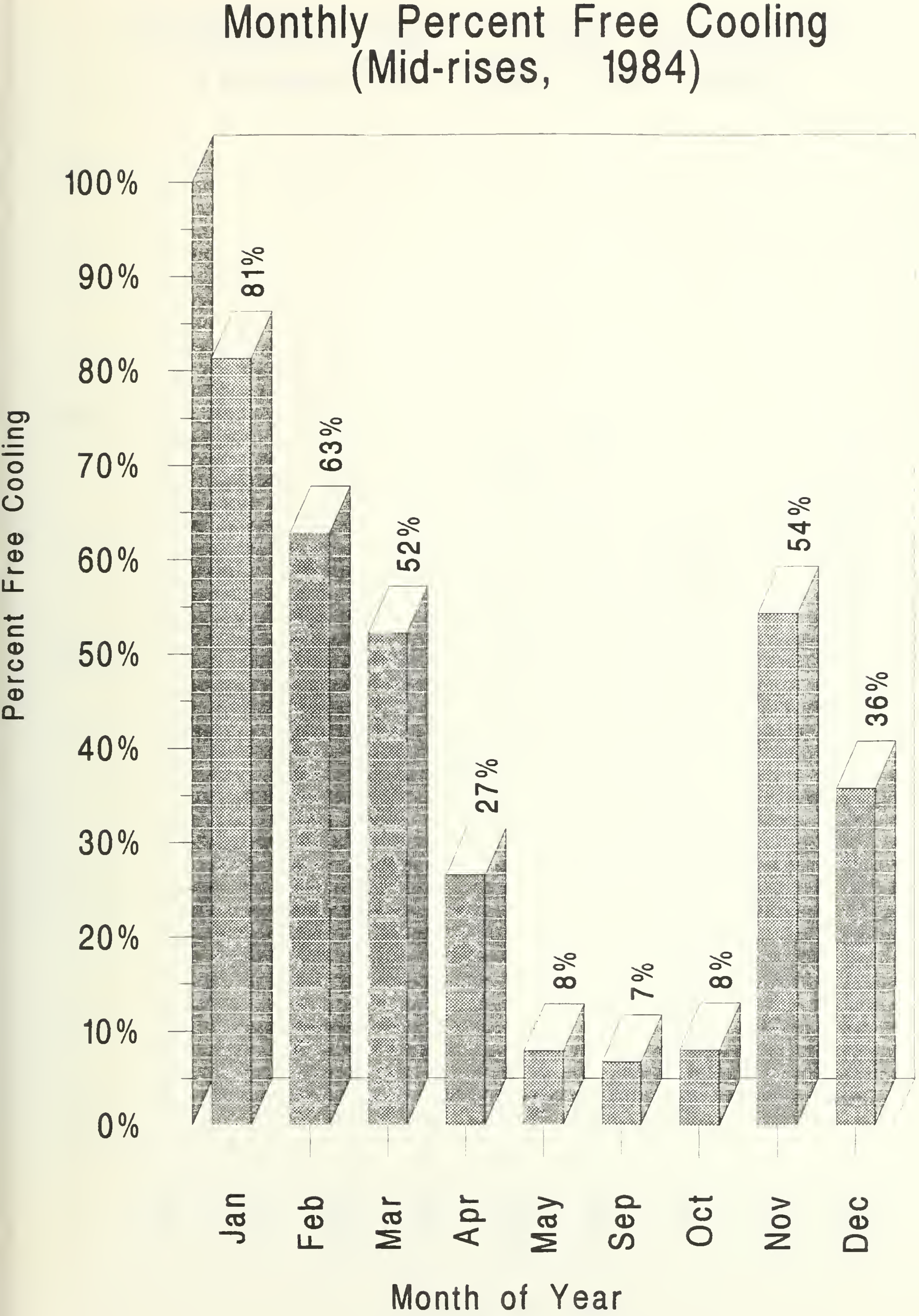


Monthly Percent Free Cooling
(Mid-rises, 1982)

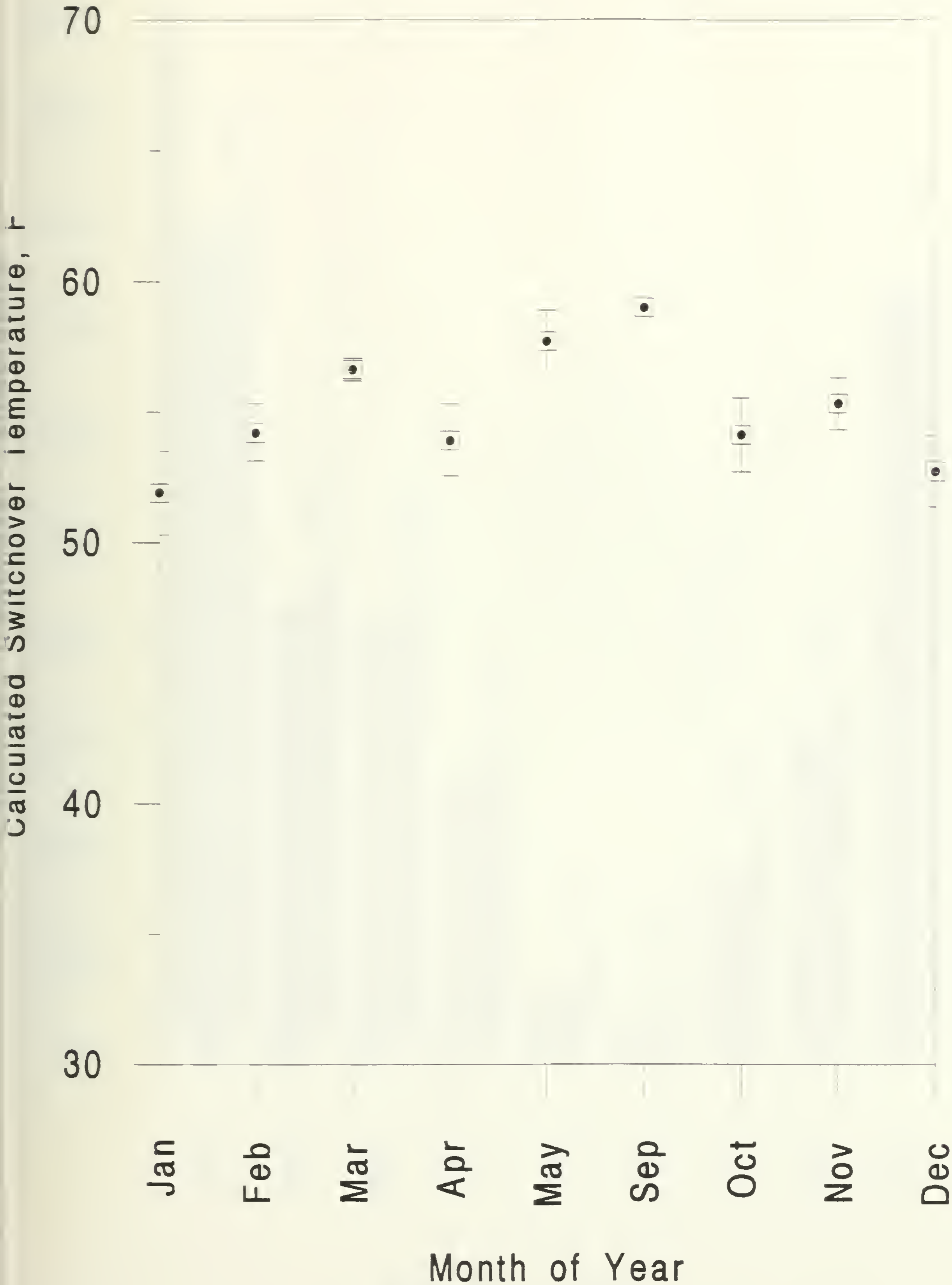


Calculated Free Cooling Switchover Temperature (Mid-rises, 1982)

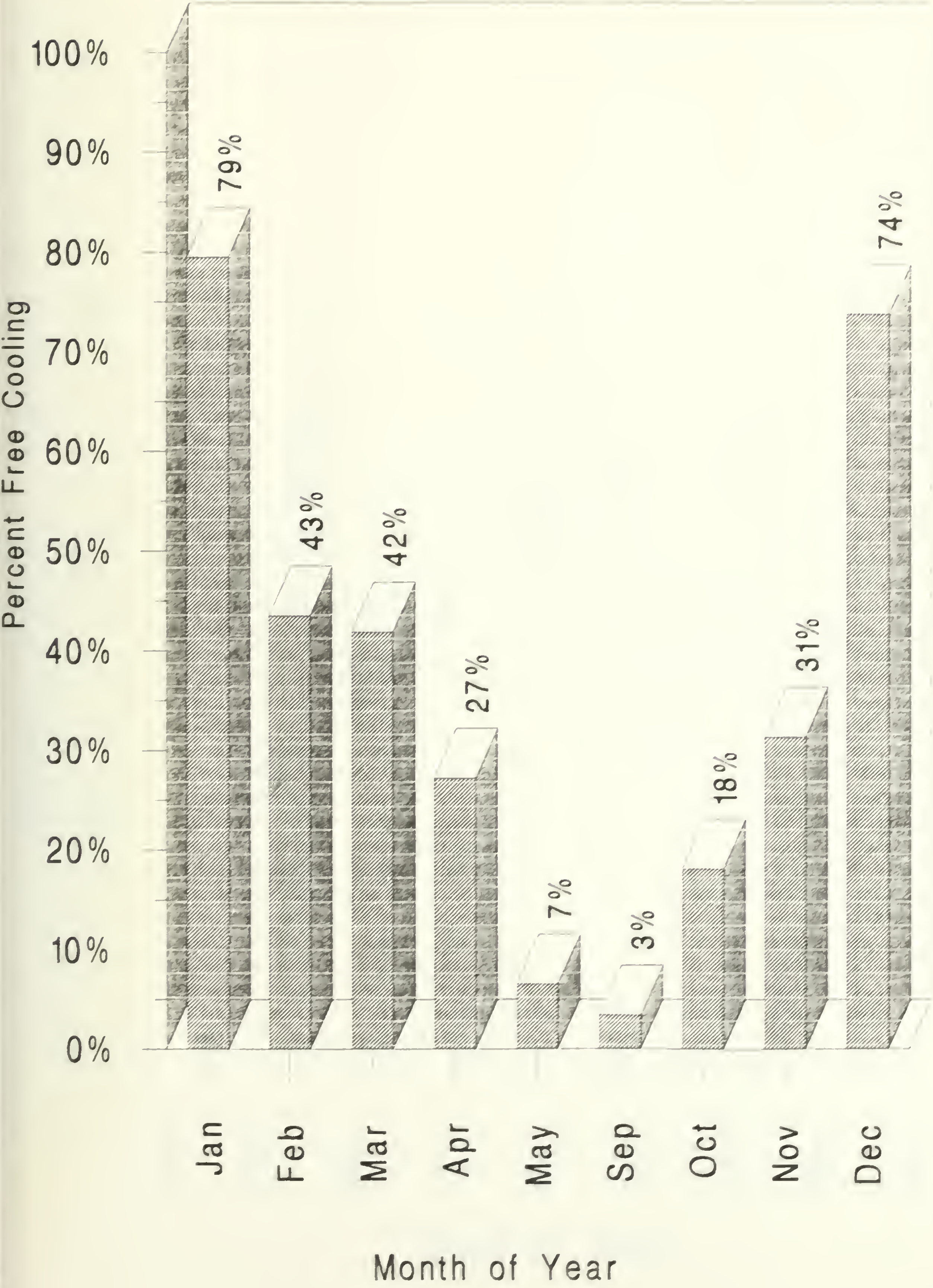



Monthly Percent Free Cooling
(Mid-rises, 1984)
Percent Free Cooling
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
81%
63%
52%
27%
8%
7%
8%
54%
36%
Jan
Feb
Mar
Apr
May
Sep
Oct
Nov
Dec
Month of Year

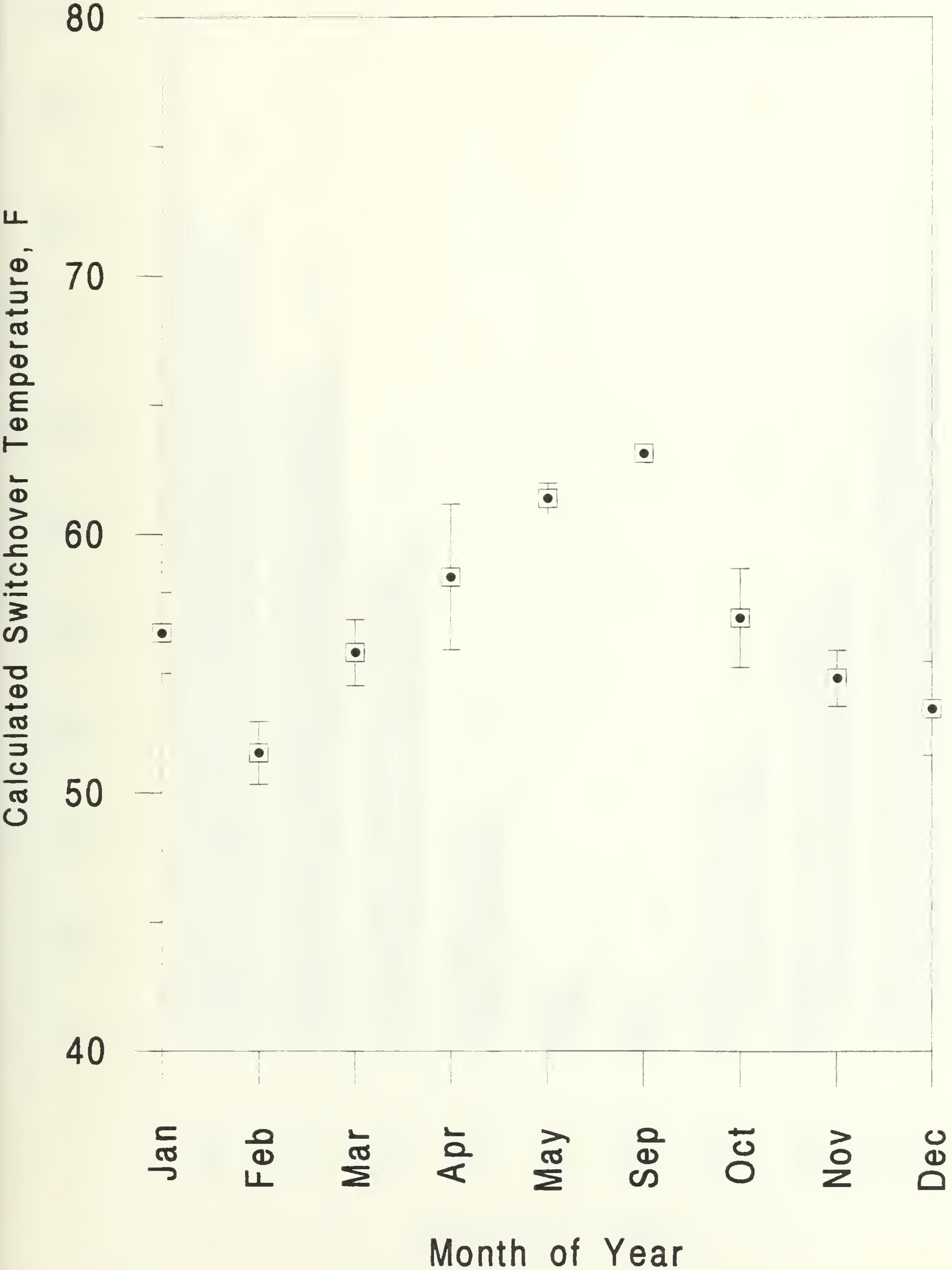
Calculated Free Cooling Switchover Temperature (Mid-rises, 1984)



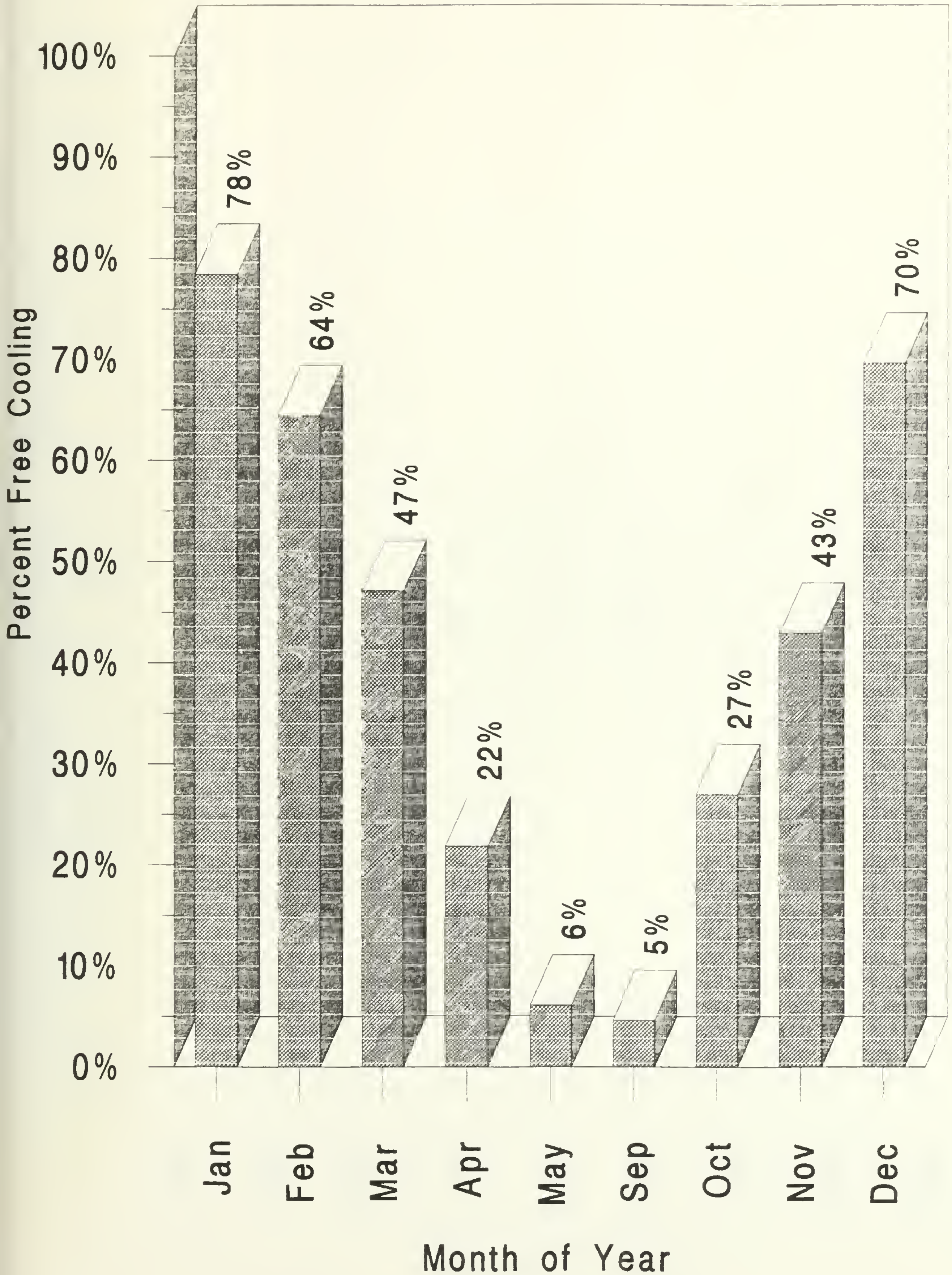
Monthly Percent Free Cooling
(Mid-rises, 1986)



Calculated Free Cooling Switchover Temperature, (Midrises, 1986)



Monthly Percent Free Cooling
(Mid-rises, 1988)



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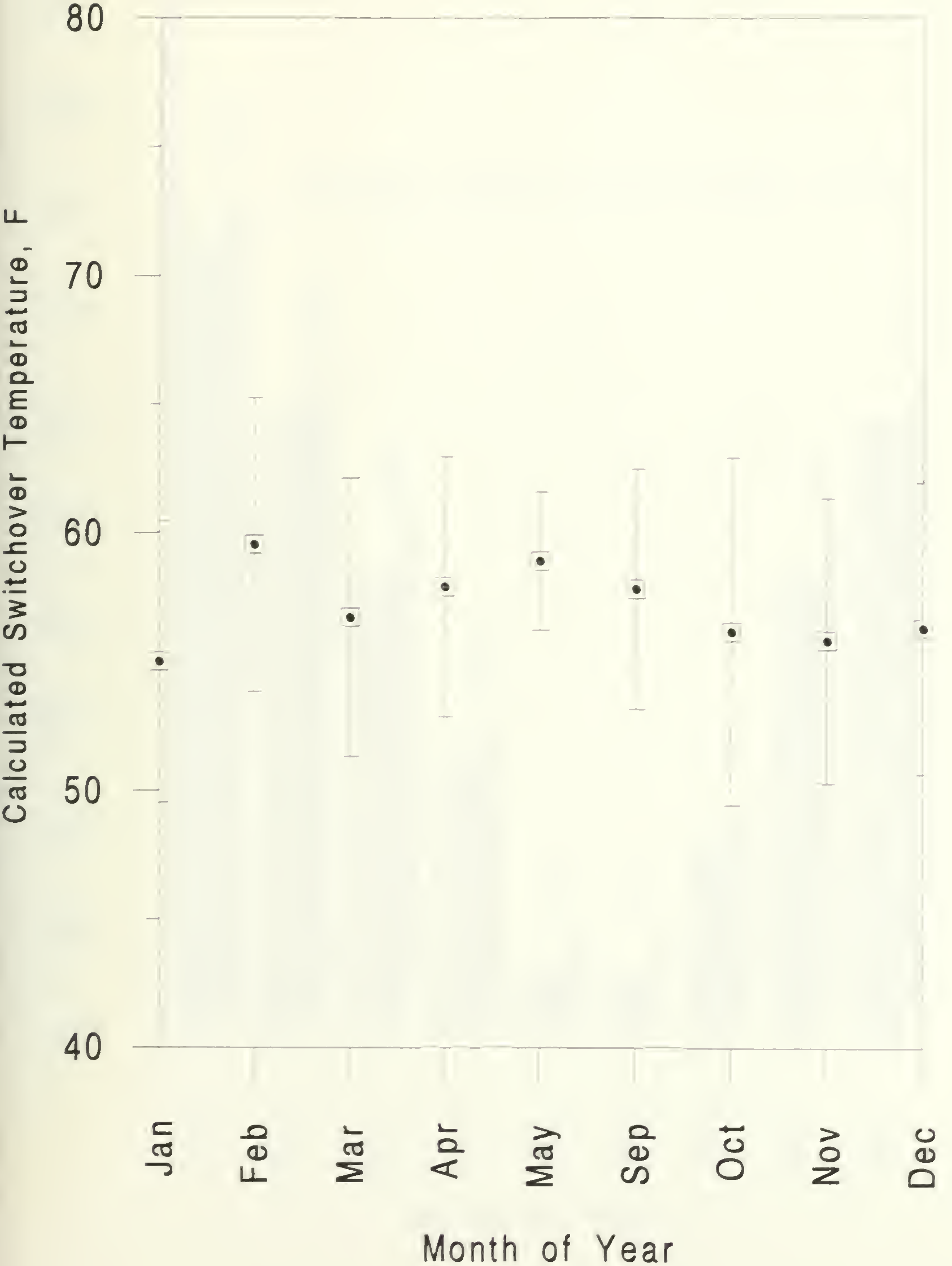
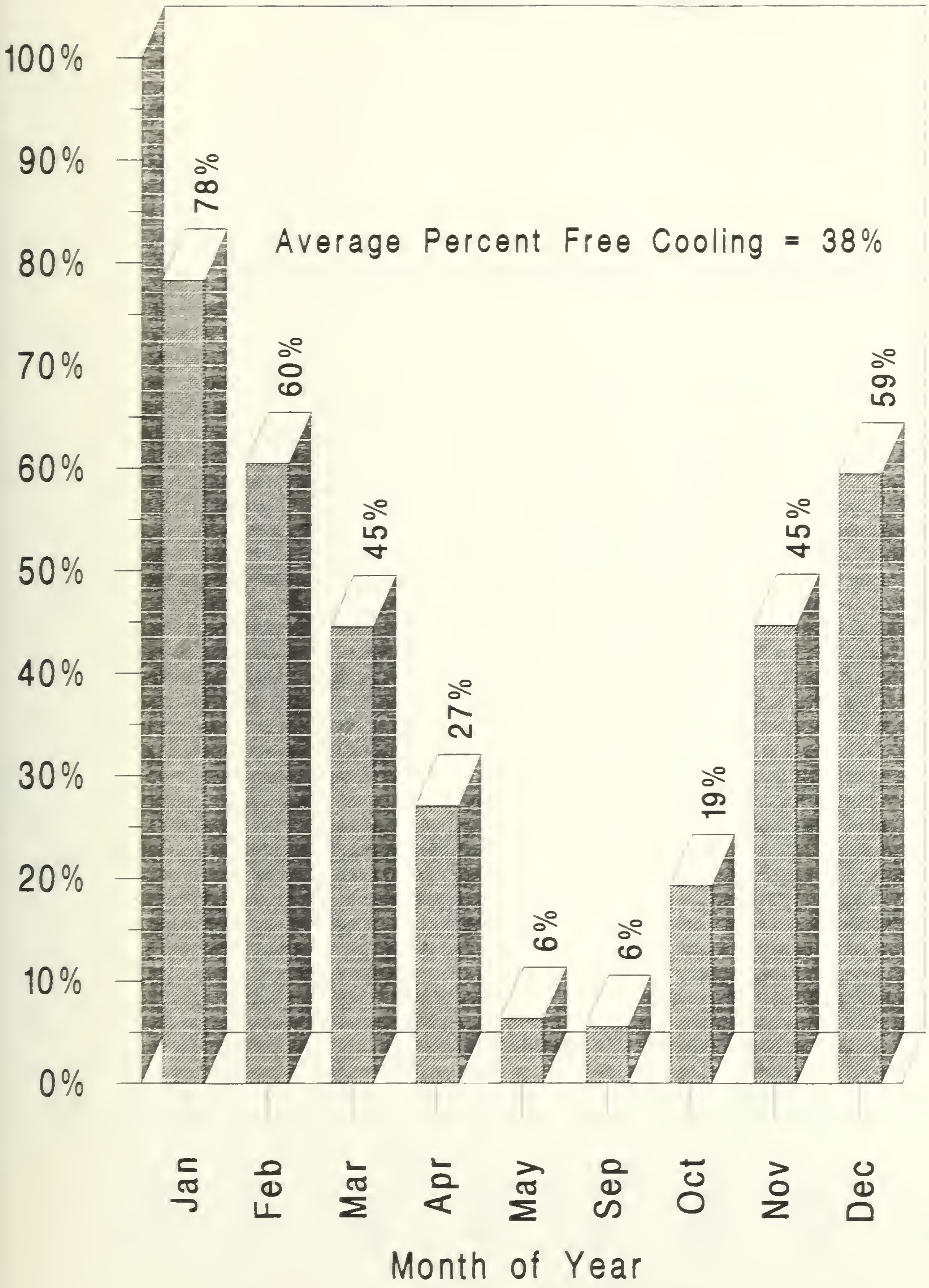
Calculated Free Cooling Switchover Temperature, (Mid-rises, 1988)

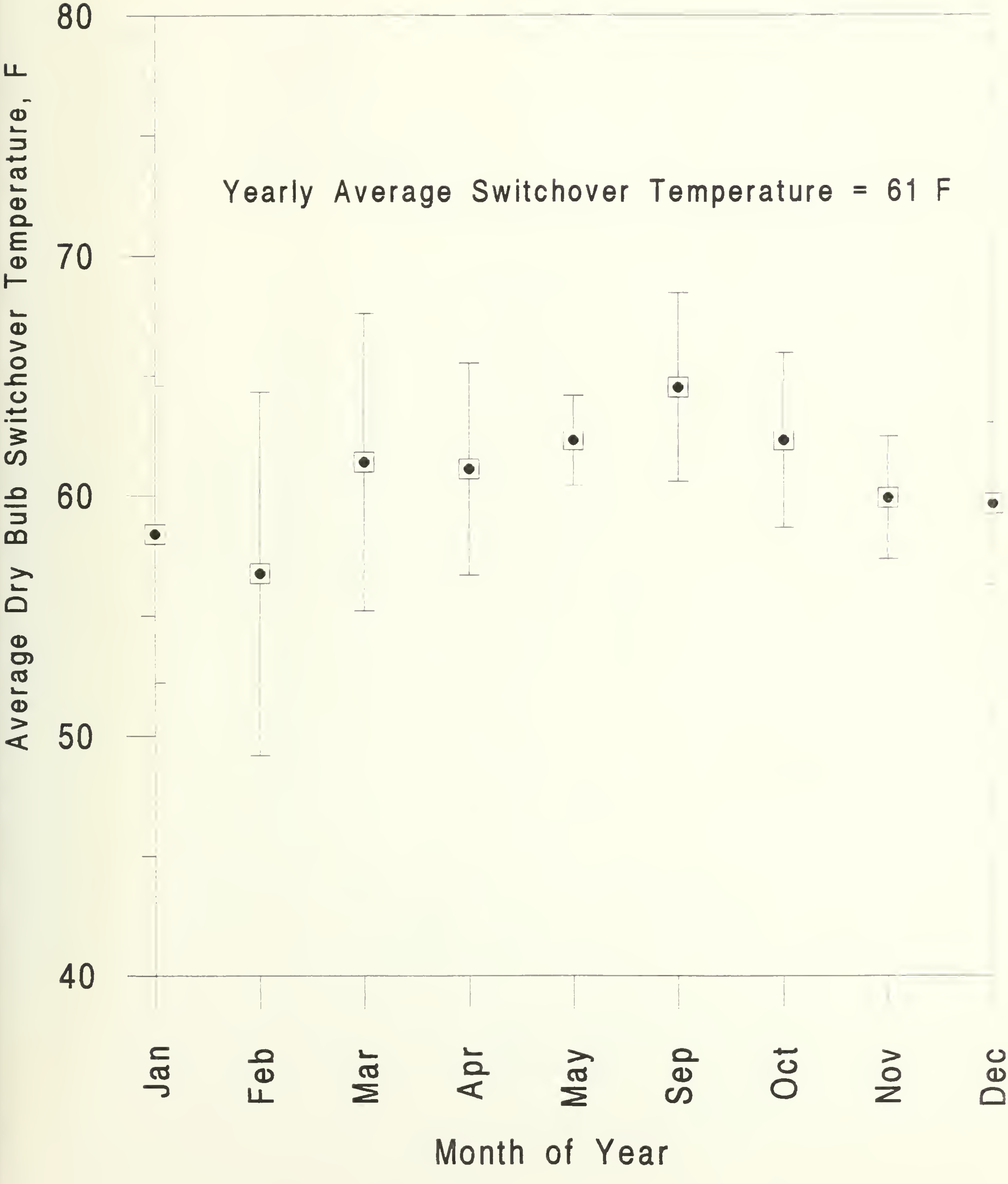


Monthly Avg. Percent Free Cooling, Midrises
(Summary, All Years)



Average Percent Free Cooling = 38%

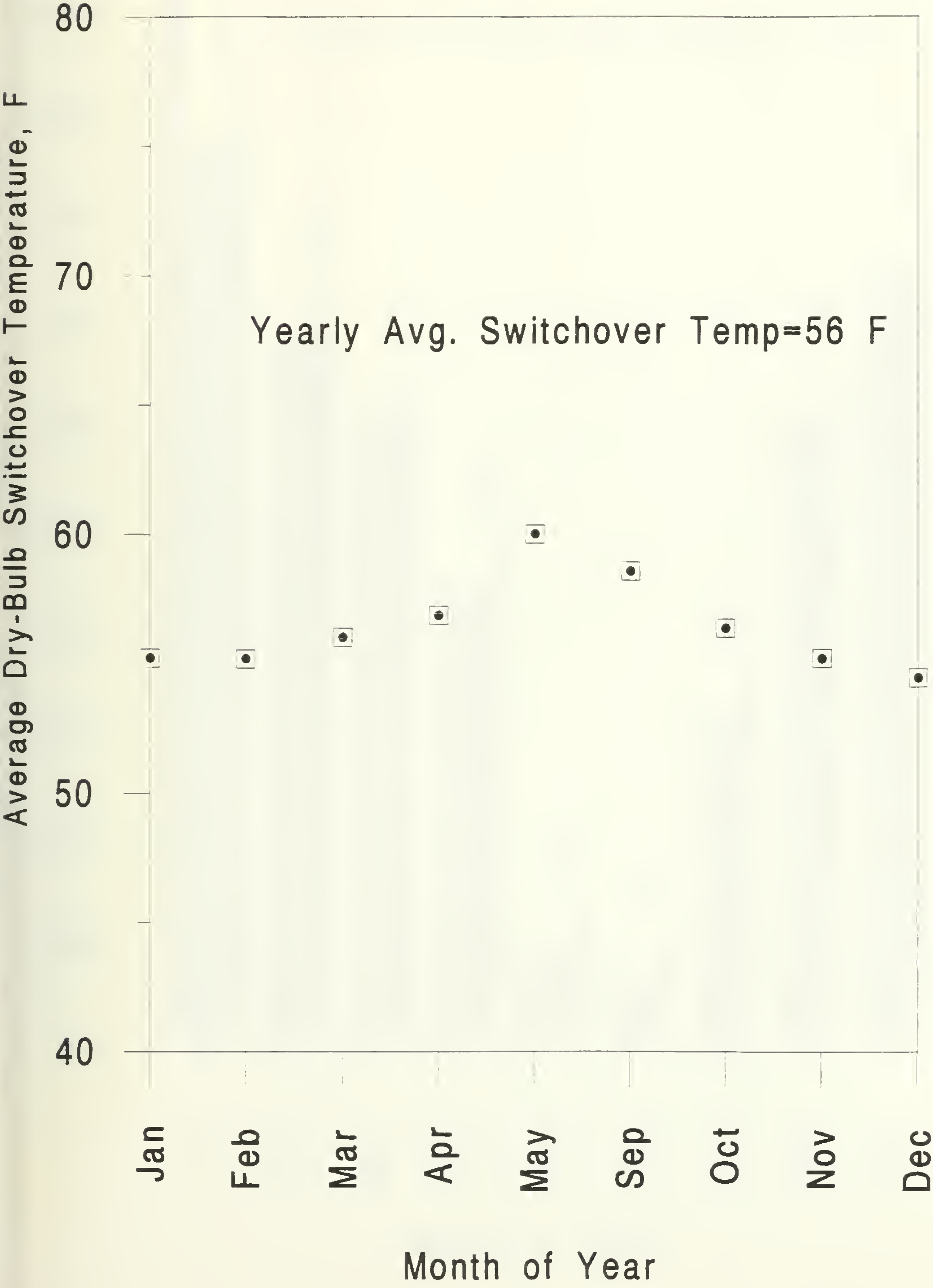
Calculated Free Cooling Switchover Temperature for Lowrise Buildings (Summary, All Years)



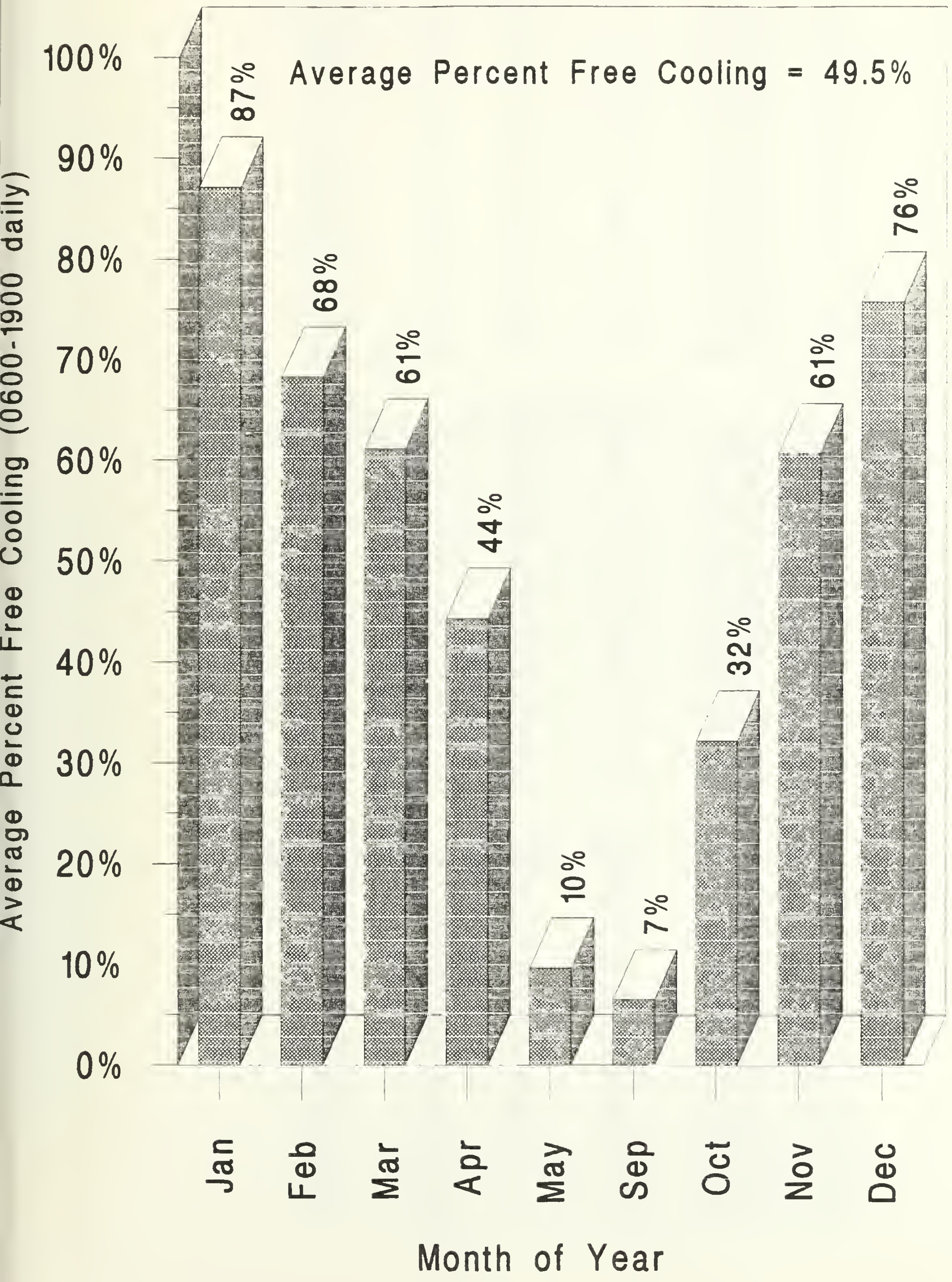
APPENDIX B

TABLE I	1982 Summary
TABLE II	1984 Summary
TABLE III	1986 Summary
TABLE IV	1988 Summary
TABLE V	Program TSET.BAS

Calculated Free Cooling Switchover Temperature for Midrise Buildings (Summary, All Years)



Monthly Avg. Percent Free Cooling, Lowrises (Summary, All Years)



[illegible]

[illegible]

[illegible]

TABLE I 1982 SUMMARY

Jan-82		Tmin=-5	Tmax=71		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	24	100	124	80.65%	56
28/32	96	177	273	64.84%	47
41	28	130	158	82.28%	58
47	25	153	178	85.96%	62
53	102	82	184	44.57%	40
56	27	144	171	84.21%	59
60/62	47	83	130	63.85%	46
64	80	84	164	51.22%	43
70/76	10	117	127	92.13%	65
211	24	141	165	85.45%	61
219	31	141	172	81.98%	57
223	30	126	156	80.77%	56
245	33	140	173	80.92%	56
Feb-82		Tmin=22	Tmax=76		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	32	126	158	79.75%	58
28/32	152	119	271	43.91%	7
41	39	136	175	77.71%	57
47	30	194	224	86.61%	61
53	92	160	252	63.49%	53
56	38	162	200	81.00%	59
60/62	43	150	193	77.72%	57
64	100	190	290	65.52%	54
70/76	6	168	174	96.55%	0
211	188	88	276	31.88%	43
219	41	230	271	84.87%	61
223	97	143	240	59.58%	51
245	47	200	247	80.97%	59
Mar-82		Tmin=25	Tmax=84		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	72	130	202	64.36%	65
28/32	256	83	339	24.48%	50
41	105	105	210	50.00%	60
47	130	90	220	40.91%	56
53	171	64	235	27.23%	2
56	126	91	217	41.94%	57
60/62	103	44	147	29.93%	53
64	237	195	432	45.14%	58
70/76	48	209	257	81.32%	70
211	201	84	285	29.47%	53
219	124	144	268	53.73%	62
223	198	67	265	25.28%	51
245	181	61	242	25.21%	51

TABLE I 1982 SUMMARY

Apr-82		Tmin=29	Tmax=78		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	99	112	211	53.08%	63
28/32	161	201	362	55.52%	54
41	142	66	208	31.73%	57
47	141	66	207	31.88%	57
53	158	110	268	41.04%	60
56	145	90	235	38.30%	59
60/62	131	94	225	41.78%	60
64	231	70	301	23.26%	55
70/76	99	79	178	44.38%	61
211	166	60	226	26.55%	56
219	144	117	261	44.83%	61
223	200	50	250	20.00%	52
245	191	66	257	25.68%	56
May-82		Tmin=51	Tmax=92		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	178	17	195	8.72%	64
28/32	482	28	510	5.49%	63
41	218	11	229	4.80%	63
47	224	12	236	5.08%	63
53	259	18	277	6.50%	63
56	207	14	221	6.33%	63
60/62	249	10	259	3.86%	61
64	384	15	399	3.76%	61
70/76	185	9	194	4.64%	63
211	226	12	238	5.04%	63
219	264	13	277	4.69%	63
223	249	5	254	1.97%	58
245	258	0	258	0.00%	
Jun-82		Tmin=58	Tmax=92		
Building No.	Chiller	By-Pass	Total	% By-Pass	Tset
20/26	231	13	244	5.33%	69
28/32	655		655	0.00%	
41	279	11	290	3.79%	68
47	286	13	299	4.35%	68
53	322	15	337	4.45%	68
56	290	15	305	4.92%	69
60/62	266	13	279	4.66%	68
64	650	0.5	650.5	0.08%	59
70/76	234	18	252	7.14%	69
211	295	13	308	4.22%	68
219	390	7	397	1.76%	66
223	299		299	0.00%	
245	289		289	0.00%	

TABLE I 1982 SUMMARY

Jul-82		Tmin=67	Tmax=93		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	241.9	11.4	253.3	4.50%	71
28/32	261.6	0	261.6	0.00%	67
41	248.8	12.1	260.9	4.64%	78
47	241.7	12.3	254	4.84%	78
53	336	5	341	1.47%	70
56	316.9	15.4	332.3	4.63%	71
60/62	230	8.8	238.8	3.69%	71
64	702.4	0.5	702.9	0.07%	68
70/76	253.4	12.5	265.9	4.70%	71
211	285.5	11.9	297.4	4.00%	71
219	317.2	4.5	321.7	1.40%	70
223	300.4	0	300.4	0.00%	
245	329.6	0	329.6	0.00%	
Aug-82		Tmin=65	Tmax=92		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	250	15	265	5.66%	70
28/32	273	9	282	3.19%	68
41	255	10	265	3.77%	69
47	250	9	259	3.47%	68
53	361		361	0.00%	
56	331	16	347	4.61%	69
60/62	234	6	240	2.50%	68
64	577		577	0.00%	
70/76	252	20	272	7.35%	70
211	294	13.7	307.7	4.45%	69
219	317		317	0.00%	
223	296		296	0.00%	
245	270	1	271	0.37%	66
Sep-82		Tmin=47	Tmax=89		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	226	33	259	12.74%	64
28/32	333	23	356	6.46%	61
41	232	12	244	4.92%	60
47	233	15	248	6.05%	60
53	316	56	372	15.05%	65
56	255	38	293	12.97%	64
60/62	217	37	254	14.57%	65
64	444	24	468	5.13%	60
70/76	196	17	213	7.98%	62
211	261	14	275	5.09%	60
219	216	4	220	1.82%	55
223	284	2	286	0.70%	
245	305		305	0.00%	

TABLE I 1982 SUMMARY

Oct-82		Tmin=39	Tmax=83		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	147	101	248	40.73%	64
28/32	206	87	293	29.69%	61
41	189	53	242	21.90%	58
47	202	32	234	13.68%	54
53	313	107	420	25.48%	59
56	223	44	267	16.48%	55
60/62	170	64	234	27.35%	60
64	334	177	511	34.64%	63
70/76	126	94	220	42.73%	65
211	230	34	264	12.88%	53
219	255	130	385	33.77%	63
223	202	108	310	34.84%	63
245	219	51	270	18.89%	56
Nov-82		Tmin=31	Tmax=78		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	49	170	219	77.63%	65
28/32	89	129	218	59.17%	58
41	114	99	213	46.48%	54
47	124	79	203	38.92%	52
53	154	224	378	59.26%	58
56	142	87	229	37.99%	52
60/62	91	119	210	56.67%	57
64	174	270	444	60.81%	58
70/76	72	131	203	64.53%	60
211	149	88	237	37.13%	52
219	165	182	347	52.45%	56
223	102	144	246	58.54%	58
245	131	140	271	51.66%	55
Dec-82		Tmin=25	Tmax=73		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	42	169	211	80.09%	63
28/32	54	157	211	74.41%	61
41	86	115	201	57.21%	55
47	91	111	202	54.95%	54
53	126	159	285	55.79%	54
56	103	137	240	57.08%	55
60/62	81	117	198	59.09%	56
64	87	168	255	65.88%	58
70/76	33	95	128	74.22%	61
211	115	141	256	55.08%	54
219	105	216	321	67.29%	59
223	84	113	197	57.36%	55
245	89	148	237	62.45%	57

TABLE II 1984 SUMMARY

Jan-84		Tmin=15	Tmax=64		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	28	130	158	82.28%	51
28/32	0	206	206	100.00%	64
41	108	139	247	56.28%	45
47	97	147	244	60.25%	45
53	62	162	224	72.32%	48
56	9	280	289	96.89%	60
64	28	290	318	91.19%	54
70/76	0	127	127	100.00%	64
211	39	183	222	82.43%	51
219	9	211	220	95.91%	59
223	37	195	232	84.05%	52
245	33	262	295	88.81%	53
301	17	94	111	84.68%	52
Feb-84		Tmin=	Tmax=		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	17	169	186	90.86%	66
28/32	36	174	210	82.86%	61
41	85	157	242	64.88%	55
47	90	169	259	65.25%	55
53	57	162	219	73.97%	58
56	99	198	297	66.67%	55
64	120	222	342	64.91%	55
70/76		161	161	100.00%	
211	113	129	242	53.31%	51
219	51	209	260	80.38%	60
223	129	128	257	49.81%	50
245	87	141	228	61.84%	54
301	126	111	237	46.84%	49
Mar-84		Tmin=25	Tmax=79		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	70	139	209	66.51%	61
28/32	79	206	285	72.28%	62
41	118	154	272	56.62%	58
47	138	183	321	57.01%	58
53	122	140	262	53.44%	57
56	167	158	325	48.62%	56
64	176	212	388	54.64%	57
70/76	23	177	200	88.50%	69
211	136	120	256	46.88%	55
219	137	160	297	53.87%	57
223	145	149	294	50.68%	56
245	138	195	333	58.56%	58
301	154	108	262	41.22%	54

TABLE II 1984 SUMMARY

Apr-84		Tmin=38	Tmax=84		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	127	69	196	35.20%	56
28/32	89	122	211	57.82%	64
41	145	96	241	39.83%	58
47	272	32	304	10.53%	49
53	166	86	252	34.13%	56
56	239	249	488	51.02%	62
64	259	128	387	33.07%	56
70/76	46	161	207	77.78%	69
211	205	35	240	14.58%	50
219	217	33	250	13.20%	50
223	167	83	250	33.20%	56
245	260	58	318	18.24%	51
301	192	41	233	17.60%	51
May-84		Tmin=	Tmax=		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	206	26	232	11.21%	60
28/32	306	94	400	23.50%	65
41	235	8	243	3.29%	53
47	293	23	316	7.28%	57
53	287	38	325	11.69%	60
56	389	32	421	7.60%	57
64	474	107	581	18.42%	63
70/76	114	87	201	43.28%	
211	289	22	311	7.07%	57
219	280	22	302	7.28%	57
223	238	40	278	14.39%	61
245	350	6	356	1.69%	51
301	264	36	300	12.00%	61
Jun-84		Tmin=65	Tmax=93		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	232	10	242	4.13%	69
28/32	397	19	416	4.57%	70
41	253	12	265	4.53%	70
47	270	2	272	0.74%	61
53	351	14	365	3.84%	69
56	429	12	441	2.72%	68
64	655	0	655	0.00%	
70/76	191	15	206	7.28%	71
211	347	8	355	2.25%	68
219	329	7	336	2.08%	65
223	300	10	310	3.23%	68
245	376	0	376	0.00%	
301	290	12	302	3.97%	69

TABLE II 1984 SUMMARY

Jul-84		Tmin=65	Tmax=93		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	274	11	285	3.86%	68
28/32	648	3	651	0.46%	66
41	290	11	301	3.65%	68
47	274	0	274	0.00%	
53	343	11	354	3.11%	68
56	400	2	402	0.50%	66
64	568	0	568	0.00%	
70/76	199	9	208	4.33%	68
211	318	2	320	0.63%	66
219	307	13	320	4.06%	68
223	279	13	292	4.45%	68
245	357	0	357	0.00%	
301	267	12	279	4.30%	68
Aug-84		Tmin=63	Tmax=89		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	284	13	297	4.38%	70
28/32	698	0	698	0.00%	
41	314	12	326	3.68%	70
47	300	12	312	3.85%	70
53	357	13	370	3.51%	70
56	398	14	412	3.40%	70
64	567	0	567	0.00%	
70/76	259	13	272	4.78%	70
211	422	12	434	2.76%	70
219	319	13	332	3.92%	70
223	312	13	325	4.00%	70
245	334	13	347	3.75%	70
301	275	13	288	4.51%	70
Sep-84		Tmin=55	Tmax=90		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	202	15	217	6.91%	59
28/32	628	21	649	3.24%	59
41	293	12	305	3.93%	59
47	235	9	244	3.69%	59
53	264	20	284	7.04%	59
56	340	16	356	4.49%	59
64	361	152	513	29.63%	59
70/76	121	31	152	20.39%	59
211	347	15	362	4.14%	59
219	266	11	277	3.97%	59
223	268	11	279	3.94%	59
245	356	10	366	2.73%	59
301	253	11	264	4.17%	59

TABLE II 1984 SUMMARY

Oct-84		Tmin=44	Tmax=85		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	219	28	247	11.34%	63
28/32	334	29	363	7.99%	62
41	302	29	331	8.76%	62
47	275	20	295	6.78%	61
53	257	37	294	12.59%	64
56	268	26	294	8.84%	63
64	347	37	384	9.64%	63
70/76	161	71	232	30.60%	68
211	366	24	390	6.15%	61
219	259	32	291	11.00%	63
223	278	0	278	0.00%	
245	387	7	394	1.78%	50
301	286	20	306	6.54%	61
Nov-84		Tmin=29	Tmax=73		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	58	129	187	68.98%	59
28/32	44	164	208	78.85%	63
41	94	131	225	58.22%	57
47	130	111	241	46.06%	53
53	95	141	236	59.75%	57
56	126	180	306	58.82%	57
64	98	230	328	70.12%	60
70/76	10	183	193	94.82%	69
211	162	134	296	45.27%	52
219	98	120	218	55.05%	56
223	138	86	224	38.39%	49
245	145	169	314	53.82%	56
301	120	163	283	57.60%	56
Dec-84		Tmin=16	Tmax=73		
Building No.	**Chiller**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	108	58	166	34.94%	53
28/32	63	122	185	65.95%	62
41	127	22	149	14.77%	44
47	116	33	149	22.15%	48
53	135	96	231	41.56%	55
56	142	131	273	47.99%	57
64	210	153	363	42.15%	55
70/76	49	127	176	72.16%	64
211	177	80	257	31.13%	52
219	137	100	237	42.19%	55
223	156	76	232	32.76%	52
245	197	219	416	52.64%	58
301	161	69	230	30.00%	51

TABLE III 1986 SUMMARY

Jan-86		Tmin=7	Tmax=72		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	17	149	166	89.8%	59
28/32	40	109	149	73.2%	54
41	43	271	314	86.3%	58
47	84	159	243	65.4%	51
53	16	205	221	92.8%	62
56	29	188	217	86.6%	58
64	16	401	417	96.2%	64
64A #1	33	94	127	74.0%	54
64A #2	471	0	471	0.0%	
70/76	0	179	179	100.0%	
211	69	206	275	74.9%	54
219	22	260	282	92.2%	61
223	60	195	255	76.5%	54
245	57	258	315	81.9%	56
301	142	129	271	47.6%	46
400 #1	0	287	287	100.0%	72
400 #2	66		66	0.0%	
Feb-86		Tmin=17	Tmax=78		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	81	93	174	53.4%	56
28/32	116	48	164	29.3%	44
41	160	123	283	43.5%	52
47	134	83	217	38.2%	50
53	71	161	232	69.4%	61
56	117	113	230	49.1%	54
64	206	103	309	33.3%	47
64A #1	241	185	426	43.4%	52
64A #2	20		20	0.0%	
70/76	51	166	217	76.5%	
211	154	108	262	41.2%	51
219	146	111	257	43.2%	52
223	134	94	228	41.2%	51
245	188	155	343	45.2%	52
301	213	94	307	30.6%	45
400 #1	87	198	285	69.5%	61
400 #2	79		79	0.0%	

TABLE III 1986 SUMMARY

Mar-86		Tmin=21	Tmax=83		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	130	83	213	39.0%	54
28/32	105	112	217	51.6%	59
41	184	119	303	39.3%	54
47	145	92	237	38.8%	54
53	97	154	251	61.4%	63
56	139	126	265	47.5%	57
64	259	149	408	36.5%	54
64A #1	321	185	506	36.6%	54
64A #2	164		164	0.0%	
70/76	106	141	247	57.1%	
211	160	90	250	36.0%	54
219	166	123	289	42.6%	56
223	172	92	264	34.8%	53
245	250	67	317	21.1%	46
301	184	178	362	49.2%	58
400 #1	141	201	342	58.8%	62
400 #2	135		135	0.0%	
Apr-86		Tmin=34	Tmax=92		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	155	75	230	32.6%	61
28/32	150	81	231	35.1%	63
41	191	120	311	38.6%	64
47	194	62	256	24.2%	59
53	139	124	263	47.1%	67
56	267	88	355	24.8%	59
64	312	8	320	2.5%	43
64A #1	121	28	149	18.8%	56
64A #2	276		276	0.0%	
70/76	150	122	272	44.9%	
211	308	40	348	11.5%	53
219	245	90	335	26.9%	59
223	233	64	297	21.5%	57
245	308	10	318	3.1%	44
301	200	72	272	26.5%	59
400 #1	33	141	174	81.0%	80
400 #2	264		264	0.0%	

TABLE III 1986 SUMMARY

May-86		Tmin=45	Tmax=89		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	226	13	239	5.4%	61
28/32	307	21	328	6.4%	61
41	307	22	329	6.7%	62
47	238	14	252	5.6%	61
53	239	21	260	8.1%	63
56	374	18	392	4.6%	60
64	503	23	526	4.4%	59
64A #1	103	18	121	14.9%	66
64A #2	473		473	0.0%	
70/76	227	31	258	12.0%	
211	324	18	342	5.3%	61
219	297	18	315	5.7%	61
223	267	15	282	5.3%	61
245	334	0	334	0.0%	
301	254	12	266	4.5%	59
400 #1	335	26	361	7.2%	62
400 #2	68		68	0.0%	
Jun-86		Tmin=65	Tmax=96		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	296	14	310	4.5%	70
28/32	240	10	250	4.0%	69
41	371	14	385	3.6%	69
47	314	13	327	4.0%	69
53	257	12	269	4.5%	70
56	423	10	433	2.3%	69
64	530	0	530	0.0%	
64A #1	184	20	204	9.8%	71
64A #2	462		462	0.0%	
70/76	262	10	272	3.7%	69
211	361	15	376	4.0%	69
219	338	23	361	6.4%	71
223	284	12	296	4.1%	70
245	357	0	357	0.0%	
301	328	10	338	3.0%	69
400 #1	129	0	129	0.0%	
400 #2	315		315	0.0%	

TABLE III 1986 SUMMARY

Jul-86		Tmin=65	Tmax=102		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	329	6	335	1.8%	72
28/32	289	12	301	4.0%	74
41	361	14	375	3.7%	73
47	308	12	320	3.8%	73
53	295	8	303	2.6%	73
56	375	6	381	1.6%	72
64	569		569	0.0%	
64A #1	231	3	234	1.3%	71
64A #2	663		663	0.0%	
70/76	295	7			
211	367	15	382	3.9%	73
219	333	13	346	3.8%	73
223	282	12	294	4.1%	74
245	386	1	387	0.3%	68
301	360	9	369	2.4%	73
400 #1	423		423	0.0%	
400 #2	253		253	0.0%	
Aug-86		Tmin=56	Tmax=93		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	361	14	375	3.7%	62
28/32	299	13	312	4.2%	63
41	477	15	492	3.0%	61
47	282	12	294	4.1%	63
53	292	5	297	1.7%	60
56	372	8	380	2.1%	60
64	578		578	0.0%	
64A #1	481		481	0.0%	
64A #2	217		217	0.0%	
70/76	288	4	292	1.4%	60
211	410	17	427	4.0%	62
219	315	15	330	4.5%	63
223	295	17	312	5.4%	67
245	390		390	0.0%	
301	319	11	330	3.3%	61
400 #1	177		177	0.0%	
400 #2	268		268	0.0%	
215 #1	212		212	0.0%	
215 #2	238		238	0.0%	

TABLE III 1986 SUMMARY

Sep-86		Tmin=58	Tmax=93		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	296	23	319	7.2%	65
28/32	264	12	276	4.3%	64
41	387	13	400	3.3%	63
47	271	10	281	3.6%	63
53	261	4	265	1.5%	62
56	304	12	316	3.8%	63
64	428	12	440	2.7%	63
64A #1	482	0	482	0.0%	
64A #2	238	0	238	0.0%	
70/76	242	8	250	3.2%	63
211	350	15	365	4.1%	64
219	289	10	299	3.3%	63
223	254	13	267	4.9%	64
245	357	0	357	0.0%	
301	276	10	286	3.5%	63
North Terr #1	98		98	0.0%	
North Terr #2	344		344	0.0%	
So. Terr. #1	158		158	0.0%	
So. Terr. #2	0		0		
Oct-86		Tmin=43	Tmax=88		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	242	33	275	12.0%	55
28/32	216	44	260	16.9%	58
41	339	65	404	16.1%	57
47	267	17	284	6.0%	52
53	242	44	286	15.4%	57
56	256	43	299	14.4%	56
64	521	108	629	17.2%	58
64A #1	18	98	116	84.5%	76
64A #2	540		540	0.0%	
70/76	179	72	251	28.7%	62
211	331	13	344	3.8%	50
219	314	17	331	5.1%	51
245	333	0	333	0.0%	
301	289	25	314	8.0%	54
North Terr #1	231	39	270	14.4%	56
North Terr #2	182	39	221	17.6%	58
So. Terr. #1	185	32	217	14.7%	56
So. Terr. #2	0	0	0		

TABLE III 1986 SUMMARY

Nov-86		Tmin=29	Tmax=82		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	106	77	183	42.1%	57
28/32	116	86	202	42.6%	57
41	164	78	242	32.2%	55
47	150	45	195	23.1%	52
53	117	56	173	32.4%	55
56	182	97	279	34.8%	55
64	170	100	270	37.0%	56
64A #1	170	211	381	55.4%	63
64A #2	173		173	0.0%	
70/76	95	89	184	48.4%	59
211	230	56	286	19.6%	50
219	182	30	212	14.2%	48
223	157	64	221	29.0%	54
245	117	64	181	35.4%	56
301	150	90	240	37.5%	56
North Terr #1	278	94	372	25.3%	53
North Terr #2			0		
So. Terr. #1	59	155	214	72.4%	67
Dec-86		Tmin=29	Tmax=70		
Building No.	**Chiller Hrs**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	11	197	208	94.7%	60
28/32	30	169	199	84.9%	55
41	80	186	266	69.9%	51
47	52	68	120	56.7%	48
53	43	158	201	78.6%	53
56	47	159	206	77.2%	53
64	54	306	360	85.0%	55
64A #1	17	340	357	95.2%	60
64A #2	122		122	0.0%	
70/76	20	177	197	89.8%	57
211	132	189	321	58.9%	49
219	100	104	204	51.0%	47
223	71	188	259	72.6%	51
245	73	163	236	69.1%	51
301	62	153	215	71.2%	51
North Terr #1	0.8	209	209.8	99.6%	70
North Terr #2	179.2		179.2	0.0%	
So. Terr. #1	8.7	310	318.7	97.3%	64

TABLE IV 1988 SUMMARY

Jan-88		Tmin=20	Tmax=70		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	5	105	110	95.5%	63
28/32	10	136	146	93.2%	61
41	34	154	188	81.9%	52
47	16	138	154	89.6%	57
53	4	103	107	96.3%	2
56	26	194	220	88.2%	56
64	33	215	248	86.7%	55
64A #1	38	122	160	76.3%	49
64A #2	13		13	0.0%	
70/76	19	143	162	11.7%	27
211	30	191	221	86.4%	55
219	5	167	172	97.1%	64
223	26	132	158	83.5%	53
245	26	144	170	84.7%	54
301	54	127	181	70.2%	46
Feb-88		Tmin=16	Tmax=73		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	29	166	195	85.1%	62
28/32	31	130	161	80.7%	60
41	211	115	326	35.3%	44
47	115	62	177	35.0%	44
53	92	155	247	62.8%	52
56	82	151	233	64.8%	53
64	70	193	263	73.4%	57
64A #1	73	208	281	74.0%	58
64A #2	31		31	0.0%	
70/76	43	180	223	19.3%	36
211	84	168	252	66.7%	54
219	33	191	224	85.3%	62
223	49	177	226	78.3%	59
245	60	146	206	70.9%	56
301	92	149	241	61.8%	52

TABLE IV 1988 SUMMARY

Mar-88		Tmin=26	Tmax=79		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	101	120	221	54.3%	60
28/32	65	141	206	68.4%	64
41	103	218	321	67.9%	64
47	99	146	245	59.6%	62
53	110	153	263	58.2%	61
56	149	125	274	45.6%	57
64	223	155	378	41.0%	55
64A #1	228	232	460	50.4%	59
64A #2	48		48	0.0%	
70/76	51	219	270	18.9%	45
211	184	112	296	37.8%	53
219	110	153	263	58.2%	61
223	149	112	261	42.9%	56
245	190	75	265	28.3%	48
301	206	80	286	28.0%	48
Apr-88		Tmin=40	Tmax=89		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	182	38	220	17.3%	57
28/32	147	74	221	33.5%	63
41	271	46	317	14.5%	57
47	192	60	252	23.8%	60
53	177	91	268	34.0%	63
56	177	78	255	30.6%	62
64	305	56	361	15.5%	57
64A #1	370	80	450	17.8%	58
64A #2			0		
70/76	216	42	258	83.7%	77
211	246	42	288	14.6%	57
219	191	93	284	32.7%	63
223	193	59	252	23.4%	60
245	269	34	303	11.2%	55
301	253	5	258	1.9%	45

TABLE IV 1988 SUMMARY

May-88		Tmin=50	Tmax=90		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	232	17	249	6.8%	60
28/32	212	35	247	14.2%	64
41	303	17	320	5.3%	60
47	229	17	246	6.9%	60
53	224	43	267	16.1%	65
56	315	33	348	9.5%	62
64	425	14	439	3.2%	57
64A #1	372	15	387	3.9%	57
64A #2	51		51	0.0%	
70/76	291	17	308	94.5%	87
211	309	12	321	3.7%	57
219	322	26	348	7.5%	61
223	303	15	318	4.7%	59
245	344	0	344	0.0%	
301	274	1	275	0.4%	51
Jun-88		Tmin=56	Tmax=97		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	276	13	289	4.5%	66
28/32	337	12	349	3.4%	64
41	351	12	363	3.3%	64
47	295	11	306	3.6%	64
53	300	20	320	6.3%	68
56	378	14	392	3.6%	64
64	472	12	484	2.5%	63
64A #1	402	9	411	2.2%	63
64A #2	248		248	0.0%	
70/76	298	10	308	96.8%	96
211	357	11	368	3.0%	64
219	340	14	354	4.0%	65
223	298	13	311	4.2%	65
245			0		
301	388		388	0.0%	

TABLE IV 1988 SUMMARY

Jul-88		Tmin=66	Tmax=98		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	264	13	277	4.7%	71
28/32	256	11	267	4.1%	71
41	333	11	344	3.2%	70
47	249	11	260	4.2%	71
53	288	11	299	3.7%	70
56	379	12	391	3.1%	70
64	558	11	569	1.9%	69
64A #1	169	14	183	7.7%	72
64A #2	504		504	0.0%	
70/76	289	9	298	97.0%	96
211	319	10	329	3.0%	70
219	308	10	318	3.1%	70
223	273	13	286	4.5%	71
245	0	0	0		
301	359	1	360	0.3%	68
Aug-88		Tmin=58	Tmax=95		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	309	13	322	4.0%	72
28/32	292	11	303	3.6%	72
41	382	11	393	2.8%	71
47	295	14	309	4.5%	73
53	334	12	346	3.5%	72
56	373	16	389	4.1%	72
64	596	14	610	2.3%	71
64A #1	435	15	450	3.3%	72
64A #2	93		93	0.0%	
70/76	327	10	337	97.0%	94
211	358	13	371	3.5%	72
219	387	16	403	4.0%	72
223	310	12	322	3.7%	72
245	136	0	136	0.0%	
301	418	3	421	0.7%	70

TABLE IV 1988 SUMMARY

Sep-88		Tmin=58	Tmax=90		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	266	13	279	4.7%	64
28/32	255	8	263	3.0%	63
41	334	13	347	3.7%	63
47	256	9	265	3.4%	63
53	294	15	309	4.9%	65
56	398	14	412	3.4%	63
64	587	15	602	2.5%	63
64A #1	89	15	104	14.4%	68
64A #2	496		496	0.0%	
70/76	290	10	300	96.7%	88
211	295	13	308	4.2%	64
219	329	15	344	4.4%	64
223	261	12	273	4.4%	64
245	329		329	0.0%	
301	301	2	303	0.7%	59
Oct-88		Tmin=40	Tmax=79		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	69	157	226	69.5%	67
28/32	88	146	234	62.4%	66
41	291	25	316	7.9%	51
47	177	50	227	22.0%	55
53	57	198	255	77.6%	69
56	160	146	306	47.7%	63
64	204	240	444	54.1%	64
64A #1	487	14	501	2.8%	47
64A #2	38		38	0.0%	
70/76	67	222	289	23.2%	56
211	233	48	281	17.1%	54
219	270	25	295	8.5%	51
223	168	75	243	30.9%	59
245	286	31	317	9.8%	51
301	230	50	280	17.9%	54

TABLE IV 1988 SUMMARY

Nov-88		Tmin=34	Tmax=75		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	87	158	245	64.5%	61
28/32	86	128	214	59.8%	60
41	148	100	248	40.3%	56
47	128	114	242	47.1%	58
53	55	201	256	78.5%	64
56	120	245	365	67.1%	61
64	149	303	452	67.0%	61
64A #1	339	27	366	7.4%	45
64A #2	178		178	0.0%	
70/76	43	240	283	15.2%	48
211	218	77	295	26.1%	52
219	212	73	285	25.6%	52
223	108	140	248	56.5%	59
245	160	89	249	35.7%	55
301	230	59	289	20.4%	51
Dec-88		Tmin=22	Tmax=68		
Building No.	**Chiller Hours**	**By-Pass**	**Total**	**% By-Pass**	**Tset**
20/26	22	131	153	85.6%	61
28/32	40	128	168	76.2%	59
41	108	142	250	56.8%	52
47	60	108	168	64.3%	55
53	6	247	253	97.6%	66
56	63	207	270	76.7%	59
64	90	367	457	80.3%	60
64A #1	79		79	0.0%	
64A #2	44	201	245	82.0%	61
70/76	11	211	222	5.0%	31
211	35	126	161	78.3%	59
219	0	122	122	100.0%	
223	129	99	228	43.4%	47
245	129	184	313	58.8%	52
301	59	82	141	58.2%	52

Thesis
O5789 O'Neill
c.1 Analysis of chilled water free cooling at the Perimeter Center Office Park (Atlanta, Georgia).

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